MODERN METHODS OF WELDING

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AS APPLIED TO

WORKSHOP PRACTICE

DESCRIBING VARIOUS METHODS

OXY-ACETYLENE WELDING
OXY-HYDROGEN WELDING
LEAD BURNING
THERMIT WELDING
ELECTRIC ARC WELDING
ELECTRIC BUTT WELDING
ELECTRIC SEAM WELDING
ELECTRIC SPOT WELDING
MIRROR WELDING
CUTTING IRON AND STEEL
EYE-PROTECTION IN WELDING OPERATIONS
AMERICAN METHODS

BY

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PREFACE

We live in a world of wonders. The life of each one of us is, of necessity, so hemmed in by circumstances that none can see much beyond the bounds of his own habitat. We recognise the progress of an industry which comes within our own experience, but we know little of those with which we are not in personal contact.

The pressman who clamps the plates on a modern lightning newspaper press does not see anything very startling or interesting in the work. The man who pulls levers in the pulpit of a great steelworks is not apt to realise that there has been a marvellous advance in the realm of manufacture. The attendant on a bottle-blowing machine has learned to take his work as a matter of course. It is found through the entire list of trades and occupations.

Yet each of these men is at times impressed by the remarkable advances made in some industry other than his own, because such knowledge comes to him, as it were, suddenly, not by the almost imperceptible movement which marks progress in work that is familiar.

The means which have brought about industrial development are worth studying. No armed warrior ever sprang full-grown from his cradle; no giant industry has ever come into being in a year or decade. It takes time to develop the machinery and acquaint the world with the advantages of a new aid to manufacture, to commerce, to civilisation, or to human comfort. He who reads this book can hardly fail to be impressed with the idea that no man can measure the possibilities of industrial growth. Who can say that at the close of the twentieth century "Darkest Africa" may not be under-selling us in our home markets? Who can be sure that with the development of China and the East, there may not come supremacy in industry before which our light shall pale? To-day the industry is exceptional in which there has not been an entire alteration and renewal in the machinery within the last few years.

The tale of manufacturing progress is one not half told, one which never can be told in full, because it grows faster than the ability

to record its development. In every vocation, in every city of the globe, are geniuses studying how to advance the lines of work in which they are engaged. Every year the standards that win success are set higher, yet every year witnesses increasing gains and greater triumphs.

Electricity is believed to pervade the universe. Astronomers see evidence of its action in the sun, in the stars, in the comets. Its properties are so varied, it affects substances so differently, that it is safe to say that we have as yet learned but a fraction of what mankind is destined to know about this wonderful thing. Because it so readily lends itself to the transmission of energy, we think of it as a source of power, whereas really it is but a means of transmitting power, like the endless leather belts commonly used for driving machinery.

The man who thinks he will read up a little on electricity is sometimes very much disappointed because he cannot learn at the outset, in a little primer, just what electricity is, and so advance step by step to a full knowledge of the subject. But there is no help for it. The operator of electricity to-day must begin, as did those who came before him, at the other end of the problem, and learn how electricity acts and what it does. After a time he will acquire a notion of things which will satisfy his craving for knowledge, and will cease to bother much about the theory.

Operators and others who follow the instructions in this book will soon be convinced of the great importance of welding processes to the future manufacturing and industrial world. It is the simplest possible axiom, when we stop to think (though few people ever do stop to think), that the only way in the long run for labour as a whole to get more wealth is for it to create more wealth; the only way to create more wealth is to increase productivity of labour.

The field for the further application of welding is enormous; but this further application is being delayed by lack of complete knowledge of the art, the utterly confusing, and, in many cases, diametrically opposed claims of competing interests. There is needed a cultivation of the co-operation spirit which will permit a frank, open discussion of the merits of the different processes, so that a reasonable agreement as to those merits may be reached. If there are prospective users of welding who are in doubt as to whether they should use gas or electric welding, or neither, can it be supposed that their confidence in any process will be enhanced by hearing its advocates claim that it is the only safe and economical one? I am not setting forth impracticable ideals, but rather

common-sense principles, already found successful in many business fields, the application of which is bound to yield the best results for all concerned.

It would be difficult to suggest a branch of the applied arts which has advanced more rapidly in recent years than that of electric and oxy-acetylene welding. Both processes gained status in the war; and, although some of the more extreme manifestations of their possibilities which the war encouraged are little likely to be paralleled in the early days of peace, the methods have now won for themselves a definite place in the shop routine. They have established their ability to tackle certain classes of work in an economical and satisfactory way. That both methods are destined to advance in usefulness, alike in extension and intension, there is no question; and, although they are in the hands of specialist firms, the general shop manager of the not far distant future is likely to find that he is expected to be able to apply them. Moreover, not only the manager, but others, both the engineers and the "semi-skilled," are likely to find interest and profit in these processes. There is probably no other recent improvement in applied mechanics which has received the scientific study devoted to autogenous welding. The result is that its practice has become an art to which one must give intelligent and well-directed study if one would avail oneself of its uses.

The universal application of this process, in every branch of industry where metals are employed, makes inevitable a great demand for capable operators. It is to the advantage of all concerned that operators should understand their work and their tools, that they should be able to apply intelligently the principles involved.

INTRODUCTION

In presenting this book to the welding industry, I may say that I have devoted my whole time to the welding processes and the materials used, and they are all concisely described in their various chapters. If the readers will give attention to the following pages, they will find many points that will help them in their studies and guide them to a knowledge of the processes. In the course of eighteen years' experience of the welding industry I have found that such a book as the present is badly needed. I now make an endeavour to supply the deficiency. It is my desire to do all in my power to raise the status of welders in this country; and this will be best achieved if they can be induced to pursue a course which will make them proficient.

Some time ago an effort was made to establish a system of certificates of proficiency for operators, but unity between the associations interested is not yet sufficient to allow this.

In the comparatively limited space available for my purpose, I have attempted to give a clear and consecutive description of the principles upon which an industry of unsurpassed importance is based. With the object of accomplishing my task, however, in a manner at once agreeable and instructive, I have now and again departed from the general plan to dwell on some particular point.

While sensible of the defects in my book, I venture to hope that to those practically engaged or interested in the conduct of numerous processes covered by its title it may prove to be of service.

I take this opportunity of acknowledging my gratitude for assistance from Messrs. British Oxygen Company, Ltd., Messrs. Charles Bingham and Company, Ltd., Messrs. Leeds and Butterfield, Messrs. British Insulated and Helsby Cables, Ltd., and H. M. Hobart, President of the American Welding Society.

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CHAPTER I

WELDING IN GENERAL

It is well known to everyone who takes an interest in welding and welding processes that the existing opinion as to the value of the processes and the practical results obtained is in a state of uncertainty. The chief ground for this uncertainty lies in the fact that these new processes have only been introduced recently into industrial practice, and rest entirely on an empirical basis. Although oxy-acetylene welding is now extensively used, and is of great theoretical and practical interest, it has never been made the object of systematic and exhaustive research.

The author has had eighteen years' experience of welding, and has made exhaustive tests and long studies, not only of what is being done in this country, but also of the progress made in the United States and Germany. The latter country is far more advanced than Great Britain. The Germans have carried out systematic and exhaustive researches. Their operators are scientifically trained, are taught metallurgy and chemistry, including the chemical compositions and melting-points of all metals and oxides, make test-pieces for experimenting with the chemical and mechanical tests, and employ microscopic and macroscopic examinations, both of the melted zone and the neighbouring parts. Their welding, as a rule, is very neat, as they are not allowed to execute commercial work until they have become fully proficient.

The introduction of oxy-acetylene welding has opened up an enormous field, in which any metal can be dealt with, and such an article as a cracked motor frame or cylinder can be rapidly welded. In these directions there seems to be ample scope for the application of engineering skill, and recent developments have shown that it is difficult to put a limit to the purpose to which engineers may yet apply the process.

To-day the business has grown beyond the limits of personal supervision. The necessity for organised instruction of operators is becoming more and more obvious in the interest of both work-

men and employer. Several welding schools have now been started in various centres about the country, whence a stream of qualified welders is already beginning to flow to the workshops, where most of them are able to turn their training to practical use.

They teach the operator under practical conditions the right flame for different work, the principles on which the blowpipe is constructed, the way to handle it, and a variety of technical and theoretical points, which are always useful to him in his subsequent career. He is also taught thoroughly the construction, working, and maintenance of the plant.

It is the operator of to-day, well instructed in the points, whom we hope to find the professional welder of to-morrow. The time is not far off when employers will refuse to engage a welder unless he can produce the certificate of proficiency. This cannot be obtained unless the operator possesses thorough knowledge and practical experience of the process.

The author has undertaken many investigations in this process. The oxy-acetylene method, when properly worked, possesses numerous marked advantages. In the first place, the operating flame can easily be controlled, and the temperature attained at various zones can be readily regulated. Secondly, the work can be easily accomplished, owing to the high temperatures reached (3,600° C.), and the appliances are convenient to handle and reliable in operation.

The most important conditions for securing good results are—

1. The use of the purest acetylene possible.

2. The use of a blowpipe so designed as to ensure accurate adjustment in the proportion of the mixed gases and to secure their exit at a velocity capable of keeping the metal sufficiently fluid without the melting flame being too rigid.

3. The use of an absolutely pure welding-rod.

4. The provision of an absolute neutral zone in the melting flame, neither oxidising nor reducing.

5. The edges must be free from all impurities, and, if over $\frac{3}{16}$ inch thick, must be bevelled.

6. The use of deoxidising agents eliminating the oxides, in view of unavoidable oxidation of the metal subject to the melting process. It is necessary to bear in mind the relation between the melting-points of the oxides and of the metal itself, which is a most important matter.

7. Rapidity in melting, in order to avoid excessive heating, which not only alters and deteriorates the original structure of

the metal, but would even favour the occlusion of the gases (particularly hydrogen) and so occasion the formation of blowholes in the melted zone.

In addition to these considerations, care should be taken that no sudden cooling occurs. The conditions may have to be modified on account of the conductivity and special dilation of the material, as well as in relation to the thickness, size, and shape of pieces operated upon.

For those who are familiar with this process of welding and cutting it is not difficult to appreciate its varied applications. The ease and rapidity with which experienced welders can carry out repairs *in situ*, and the portability of the plants, make the process valuable, if not indispensable. The service rendered by it in many workshops, where the welding of articles of all kinds is a daily necessity, is calculable.

The oxy-acetylene process occupies a leading place in all aeroplane and airship industries. It is used with advantage in welding sheet steel stampings, cylinders, aluminium crank cases and machinery parts, steel tubes, stamped steel water-jackets for cylinders, broken cast iron. Moreover, for cutting iron and steel this process has no rival whatever. It will cut wrought iron or steel plate 20 inches thick. The flame has been applied to the case-hardening of steel, and some firms are using this on a large scale. It is well known that the flame containing an excess of acetylene is a very energetic carboniser.

This process may be employed on any class of work. It will weld 30-gauge steel or 1½-inch boiler plates, cut mild steel up to 20 inches thick; weld any commercial metal, such as cast iron, aluminium, copper, bronze, zinc, lead, delta metal. In the repair of broken machinery and parts it is always above its rivals; repairs are executed quickly and can be done without dismantling in many cases. It can be used in the manufacture of safes and tanks, in the jointing of pipes, steam superheaters, casks, artistic ironwork, in adding metal to parts worn by friction, filling up holes or parts of new structure cut away in error, welding of tool steel to wrought-iron bars, and welding of copper or brass tubes. The flame can be used for preheating and for hammering and annealing after welding, thereby ensuring a soft metal, a method not practicable in the electric process.

In the welding of light sheet steels with 24-gauge metal, 45 feet per hour can be welded, with a consumption of only 4 feet of oxygen and 3 feet of acetylene. On the other hand, when the metal reaches

$\frac{3}{8}$ inch thick, electric welding has the advantage both in speed and cost.

When the process of acetylene welding was first introduced, its apparent simplicity led many engineers wrongly to assume that welding appliances might be regarded as general workshop tools, which any inexperienced but handy man could operate with success. Consequently much work was condemned wholesale because of the defects in the weld. The author would emphasise that this is not the fault of the process, but of inefficient workmen.

It is estimated that there were, during the recent war, 33,000 employed in this country in welding processes, of whom 25,000 entered the field during the war. Of the total number, 90 per cent. are not fully skilled—that is, they are incapable of executing satisfactory welds on all metals, being mostly employed on sheet steel. The impetus that has been given under war conditions should stimulate employers to investigate and exploit this revolutionary process, the possibilities of which have no obvious limits.

In the shipbuilding trade this process can be utilised very much more than at present—for instance, in making knee brackets, stays, and frames. These can all be cut and welded by blowpipes, with present costs reduced 50 per cent. and output increased. A blowpipe only requires one man; but an anglesmith, when welding a knee bracket, requires two or three assistants. Most shipyards have plants, but they are not utilised to advantage.

In all welding it is most important that the work should be adequately prepared before commencing to weld, as all time spent in this way is amply repaid afterwards in the easier execution, and also by the homogeneous nature of the weld. It is, however, a subject on which it is impossible to lay down any hard-and-fast rules, the varying nature of the work accomplished making it impossible to do so. The general principles obtained in the best practice point out that the line of weld must be opened out—that is, the two edges must be bevelled to an angle of 45 degrees, to make certain that the weld is well penetrated, not merely sealed over, and to strengthen the weld by increasing the surface of contact.

One of the most important things to do in the preparation is to arrange the pieces to be welded in such a position that there shall be no deformation, breaks, or cracks, or internal strains, and that they may be linable at the conclusion of the operation. This is a point in which the skill and experience of the operator are revealed, as there are no rules to guide him, and upon any work but that of the simplest character failure to grasp and apply the laws of expan-

sion and contraction means the partial or total ruin of the work. It is impossible to control expansion and contraction by physical force, so the only way to prevent disastrous results is to foresee the probable direction and extent of the phenomena, and nullify the effects by preheating certain parts of the work, either by the blowpipe or the welder's furnace.

It is good practice to raise the temperature to nearly red heat in the furnace and weld, then allow to cool slowly and uniformly

FIG. 1.—THE RADIOGRAPH, USED FOR CIRCULAR CUTTING, AUTOMATICALLY, AS SHOWN, IS CUTTING ANNULAR RINGS 31 INCHES DIAMETER BY 6 INCHES THICK AT A SPEED OF 7 INCHES PER MINUTE.

Note the clean cut and accuracy of the rings.

in sand or asbestos; but all cold currents of air must be avoided. All castings should be preheated bodily. This is a great advantage, for not only does it save gases, but it prevents any irregular expansion, and hence no fractures.

The cutting of iron and steel by the oxy-acetylene flame is being very extensively used. This involves the use of a blowpipe of a different design, which provides for the oxy-acetylene flame and an auxiliary jet of pure oxygen to be impinged on the line of cutting. The principle underlying this method consists of taking advantage of the fact that, when heated, iron and steel can be oxidised very quickly by a jet of oxygen, which jet, delivered at high pressure, blows away the oxide that is made, leaving a narrow, clear cut, almost as clean as a saw cut.

CHAPTER II

LEAD BURNING

THIS process is one of fusion of lead by oxy hydrogen, air hydrogen, or coal-gas hydrogen. The air-hydrogen process, dating back over one hundred years, for a considerable time was only employed in chemical work on the construction of acid tanks and vessels with their pipe connections. The tanks being built of wood, lined with sheet lead, the junction of the sheet was effected by this method. At a later period this system was employed in large gasworks, more recently for the manufacture of electric batteries and their plate connections. If solder had been used on either class of work, it would have been attacked by the acid. It was restricted on account of its cost.

In the latter part of the year 1888 a series of experiments was carried out by the Brin's (now British) Oxygen Company, with the object of using coal-gas from the ordinary town main and oxygen from a trade cylinder. After due consideration of the matter, it was thought possible to utilise the pressure of the oxygen cylinder to obtain an injection action by which the supply of coal-gas at low or main pressure could be increased and thoroughly mixed with the oxygen in the blowpipe previous to ignition. In order to complete combustion (thus preventing the formation of carbon deposits on the melted lead), after various trials had been made, the injector blowpipe which we illustrate on p. 7 was designed, and was found eminently adapted to the purpose. It fulfilled in other respects all the requirements necessary to ensure good work, and, moreover, as it produced a flame at much higher temperature than could be secured by the old hydrogen-and-air system, it enabled the plumber to execute about double the amount of work, of better quality, and without assistance.

H (Fig. 2) is the inlet for the coal-gas supply; *O* shows the injector inlet for the oxygen supply, fixed in position with the injector removed, showing the coned end which projects through the chamber into a cone formed in the body. The pipe leading away from the body is screwed at the end to take the nipple, which is of various sizes, to

deal with lead from the thinnest section up to ½ inch thick. The essential features of this type of blowpipe are the shape and design of the injector cones, with their relative position to each other; the reservoir for the coal supply provided between the two gas inlets *O*

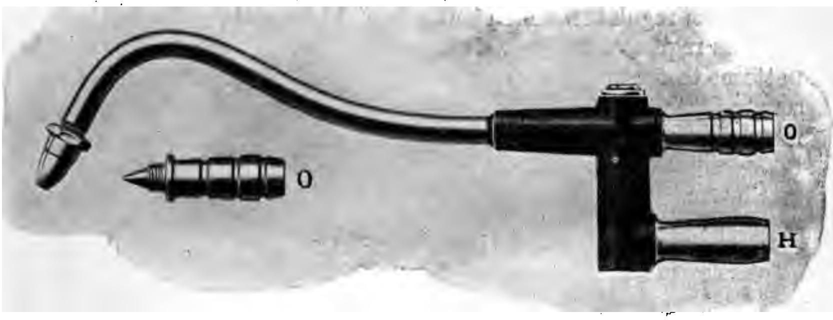


Fig. 2.—Injector Blowpipe.

and *H*; together with the mixing chamber, into which the brass pipe is screwed. The flame also differs somewhat from that of the old hydrogen type of blowpipe, its chief characteristic being a well-defined pale blue cone about a quarter of an inch long. The hottest

Fig. 3.—Shoulder Taps for Use with Lead-Burning Blowpipe.

part is the point of the cone, which, in use, impinges on the metal operated upon. Melting is clean and bright. This flame is best controlled by the use of what are known as "shoulder taps," illustrated herewith.

These taps in Fig. 3, marked *H* and *O* respectively, correspond

with those on the blowpipe, and are connected by two lengths of rubber tubing, with the twofold object of securing flexibility and lightness, the pressure being previously reduced from the other end of the tap, marked *H*. A rubber tubing leads to the ordinary coal-gas supply from the main, and the oxygen tap, marked *O*, is similarly connected by a rubber tube with the outlet of an endurance regulator, which is illustrated herewith.

This regulator in Fig. 4 is connected by a ring nut, seen at the bottom, to the oxygen cylinder. The knurled nut on the right is screwed into the diaphragm plate, indented on the sleeve, by which means it can be adjusted to maintain any constant outflow of oxygen

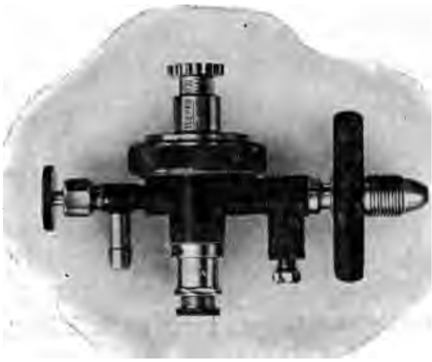
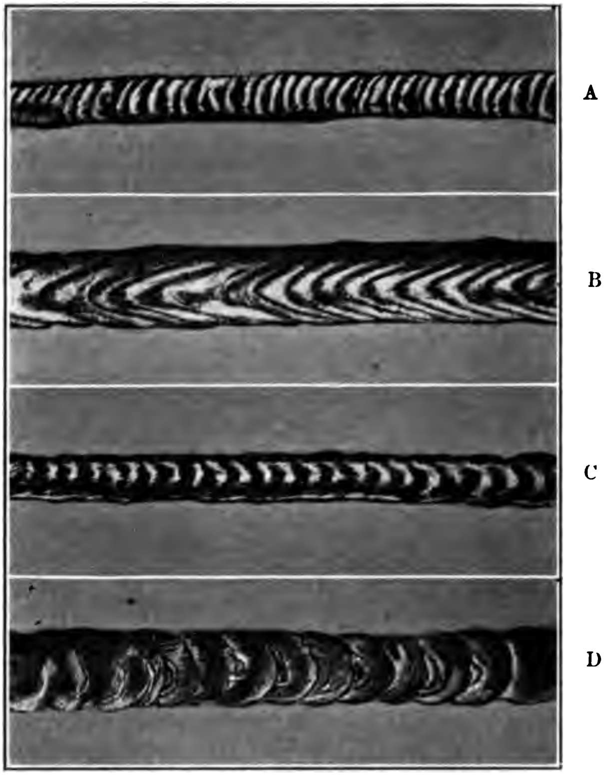


FIG. 4.—OXYGEN REGULATOR.

from the cylinder up to 30 pounds pressure per square inch. The projection immediately opposite is a safety valve, the outlet or stop valve being shown on top. These illustrations constitute a complete lead-burning outfit, with the exception of the rubber tubing and the oxygen cylinder. A sample injector blowpipe was submitted to the Gas Light and Coke Company for trial in their chemical works at Beckton, and gave satisfactory results. A large order was consequently placed. The system has met with universal approval, not only in the trades already mentioned, but also for roof work and general plumbing. If lead burning is required where there is no coal-gas supply, this can be obtained compressed in cylinders similar to those used for oxygen; but an endurance regulator would have to be used on the coal-gas cylinder. In lead burning, in order to secure sound joints in any class of work, it is necessary that the joints are scraped perfectly clean and bright, and also the strip of lead that is used for filling in the case of a butt joint.

For lap joints no filling strip is necessary. In the latter case, however, it is equally important to scrape clean all surfaces to be welded, including both the overlapping edges, otherwise it is not possible to do sound work. The illustrations represent the best methods of executing the various types of sheet-lead burning. *A* (Fig. 5) is a butt



FIGS. 5 AND 6.—LEAD-BURNED JOINTS.
A, butt joint; *B*, vertical joint; *C*, vertical lap joint; *D*, lapped joint with metal added.

joint. Where added metal is required, the line of weld should be about $\frac{5}{8}$ inch to $\frac{3}{4}$ inch wide, and thickened up. This is a very strong joint. *B* is a vertical joint, which is lapped, and no additional metal is needed. This vertical welding is not as easy as the butt. The metal when molten falls very quickly, and unless the welder is sharp the molten metal runs right down instead of in the

line of the joint. Much practice is necessary for this type of welding. *C* (Fig. 6) is a vertical lap joint, too. The same methods have to be adopted as with type *B*. This weld is not so good as type *B*, nor so neat. *D* is a lapped joint with added metal, the weld being about $\frac{5}{8}$ inch to $\frac{3}{4}$ inch wide. This is welded horizontally.

In chemical works very often the sheet lead used is 20 to 30 pounds, and when vertical jointing has to be done with this thickness it is usual to employ what is known as a moulding tool, which is held over the lap. The lead is melted and allowed to fall into this moulding tool. As soon as it is cooled, it is pushed up a bit farther, melted, and filled again, the operation being repeated until the joint line is finished. This moulding tool is simply a forged tool shaped half-round on the inside, where it fits against the lead joint; the size is about 1 inch by $\frac{1}{2}$ inch semicircular, about $\frac{1}{2}$ inch thick, with a handle at the other end. Below is an illustration of one.

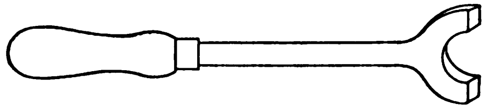


FIG. 7.—MOULDING TOOL FOR HEAVY VERTICAL WELDING.

Lead burning, so called, is the autogenous welding of lead with a gas torch. The edges of the lead parts are fused together, using no solder or other metal except pure lead to fill the joint. The term "lead burning" is really a misnomer, as metal is not burnt, but simply fused and flowed together. This process only is employed for applying lead linings of acid tanks used in chemical plants, fertiliser factories, rubber reclaiming works, electroplating shops, nitroglycerine huts, and other industries. The widespread use of storage-battery starting systems on motor-cars has created a demand in garages and battery stations for lead-welding equipment for the welding of lead connectors and terminals.

Lead welding is used to some extent in making up pipe connections; but tank and storage work are the chief applications for which lead-burning equipments are purchased. Considerable skill is required of a lead burner to weld lead sheets together without burning holes through or causing the lead to drop. But the trade is one quickly learned by an intelligent workman. Success depends on clean, thorough preparation, suitable equipment, right material and right working conditions, as well as personal skill. Two forms of joints are used, the butt and the single-lap seams. The latter are

used almost exclusively in tank burning. Butt joints are used mostly in lead-pipe jointing.

When making a butt joint, the edges of the sheets or pipes should be trimmed straight. They may be rasped to 75 to 80 degrees in opposite ways, so that when the two sheets are laid together, a **V** groove of 30 degrees or slightly less angle is formed. If a filler is to be used, the groove is filled with molten lead, flush or slightly above the surface of the sheets or pipes. A preparation of the butt joint by bevelling is practised for sheet burning except on very heavy lead—so thick, that is to say, that it is rarely used. All thicknesses up to, say, 20 pounds to the square foot are butted with square edges and generally burned together without using the filler rod. The use of the latter slows down the work, on account of the necessity of frequently cleaning off the oxide film on the rod. A joint made without the filler rod is slightly thinner than the sheet; but this is rarely objectionable. When burning a butt joint with the filler rod, the flame is played on the sheets until the metal is softened to fusing-point, but is still too stiff to flow freely. The added metal is supplied from the lead filler rod to fill the **V**, if prepared for a groove. The filling rod is held in the left hand close to the joint, so that the heat of the flame melts it and deposits molten lead into the joint, alternately heating the sheets and the filler rod to the fusing-point, letting a drop fall into place, then whipping the torch off momentarily to allow the fused metal to cool. This practice is slow and seldom necessary.

It should be borne in mind that tank linings are made of chemical lead—that is, new lead, free from impurities. Ordinary sheet lead used for gutters and other purposes is often made of old lead, and should not be used for acid tank linings which must be autogenously welded. Lap seams are always used in tank linings where a smooth surface is not absolutely required. In making a lap seam the top sheet should lap over the under sheet about $\frac{1}{2}$ inch to $\frac{5}{8}$ inch. All dirt and oxide should be removed carefully from the joint with a sharp scraper. Some lead burners prepare for welding by painting a strip of asphaltum along the edge about 1 inch wide, letting it dry, and then scraping it off about $\frac{1}{2}$ inch width next to the edge with a sharp scraper, which removes the oxide and the asphaltum. The asphaltum tends to hold from breaking down when overheated, and thus favours the use of a large flame burning at a fast rate. The flame is directed against the top sheet about $\frac{1}{4}$ inch from the edge. Some burners give the torch a circular motion, the diameter of the circular path being from $\frac{1}{2}$ inch to $\frac{5}{8}$ inch; but the most rapid work

on level seams is done with no movement except forward. The top sheet fuses and unites with the metal beneath, the edge breaks down, and the corner is filled with molten lead, which adheres to the lower sheet, making a weld about $\frac{3}{8}$ inch wide. The burner dispenses with the use of the lead filler rod or solder stick on lap seams, simply melting down the edge of the overlapping sheet, causing it to unite with the one beneath.

In vertical lap seams the torch is generally given an in-and-out motion, thus taking the flame close to the lead and then away. When the flame is close to the lead a small section of the upper sheet over the seam melts, and slides down about $\frac{1}{4}$ inch, where it cools and unites. The repetition of the torch movement causes this action to be repeated, drops of molten lead sliding down the joint, uniting each time the torch is held close. This method is used only on vertical work, where it is not feasible to do straightaway burning. Some welders give the circular motion instead of the in-and-out, but the result is practically the same.

The temperature needed for lead burning is low in comparison with that required for welding cast iron or steel, being only 62° F. A special torch is employed, which is held in the hand and manipulated somewhat the same as a soldering iron. These torches may be used with acetylene successfully.

The lead burner necessarily becomes an expert at working lead within narrow temperature ranges. He must heat the metal at the joint to the fusing-point, but not so much that it becomes liquid and drops away. When butt welding with the solder stick, he must avoid heating and adding metal so hot that when it drops into the joint it burns a hole through instead of filling the groove. He should make provision for growth or expansion of the linings of the hot tanks. Repeated heating and cooling cause the lead to expand. After a period of use the lining will be found in a corrugated condition, due to permanent expansion.

Lead burning of storage-battery connections is comparatively easy, and is quickly mastered by anyone having some mechanical skill. Handy men soon become sufficiently expert in this class of work to burn storage-battery terminals successfully. The danger to be avoided is overheating. The operator must learn to clean thoroughly the parts to be united, and to apply the flame no longer than is required to fuse the metal and bring about union. When the connections have been flowed together, the excess metal should be wiped off with a woollen cloth greased with mutton-fat or beef-tallow.

CHAPTER III

MANUFACTURE OF OXYGEN

OXYGEN is invariably the principal ingredient or combustion agent used in the cutting of iron and steel in autogenous welding with the blowpipe. It is necessary that those handling the blowpipe be familiar with its properties, manufacture, storage, and methods of use. Oxygen is the most widely distributed of all bodies. It exists in a state of mixture in the air, which contains one-fifth of its volume of this gas. Water is a compound of oxygen and hydrogen. It is a colourless, tasteless, and odourless gas. One litre of oxygen at 0° C. and atmospheric pressure weighs 1·43 grammes, its density is 1·1056, its chemical symbol O, its atomic weight 16. The characteristic property of oxygen is its power of supporting combustion; a glowing candle will instantly burst into flame if plunged in a jar of oxygen.

Iron heated to redness burns readily in air or oxygen. This unique phenomena is the whole secret of the cutting of iron and steel with a jet of oxygen (which will be described under "Cutting Iron and Steel" in a later chapter). The combustion is a chemical reaction between the oxygen and the body which burns with it. The product of the combustion is called "oxide."

The manufacture of oxygen can be carried out by several processes, some of which are the barium oxide, the electrolysis of water, and the Linde process of the fractional distillation of liquid air, which brings about the production of pure oxygen. In 1886, on the present site of the British Oxygen Company's works in Westminster, a large oxygen plant was erected, which must take a leading position in any article dealing with industrial gases. The plant was installed by Brin's (now the British) Oxygen Company. Although in itself a qualified success, it led to the development by that Company of a process which was destined to supersede all other known methods of manufacturing oxygen, and greatly to enhance the commercial value of the gas.

The Brin process of producing oxygen is based on the barium-oxide process, first suggested by the eminent chemist Boussingault in 1857. Boussingault discovered that at a temperature of about

1,000° F. the monoxide of the metal barium would absorb oxygen readily from the atmosphere, with the resulting formation of the dioxide, and that at a higher temperature of about 1,600° F. the oxygen thus absorbed would be given off again, and monoxide restored to its original condition, ready for the cycle to be repeated. Continuous efforts were made to establish a commercial process for the production of oxygen on this apparently indestructible reaction of barium oxide. In spite, however, of its chemical simplicity, many practical difficulties arose, which remained unsurmounted until the event of the Brin's Oxygen Company in 1886. The Company was formed to work the patents of the two French chemists whose names it bore. Initial experiments, conducted on a small scale under these patents, had met with considerable success, so that a large plant was laid.

It will, however, be seen from what has already been stated that the Company's old title was always somewhat of a misnomer. The process which has made them not only the oldest and leading gas compressors of the day, but also the pioneers of the gas cylinder industry, has always been more British than Brin. Although now only of historical interest, the barium process is entitled to more than a passing recognition in any description of the development of industrial oxygen, because the industry was not only founded, but was successfully conducted by means of that process for more than twenty years, during the whole of which time, although many other methods of producing oxygen were proposed and tried in this country and abroad, the barium process remained in sole possession of the field. Furthermore, it is worthy of note, in these days when it is customary to credit any country but our own with industrial enterprise, that in Germany, France, and the United States, the oxygen industry was started with the barium, designed and erected by the British Oxygen Company, who have acquired the British patents of Professor Linde and Dr. Hampson. These two inventors are the authors of the self-intensive system of liquefying air, on which are based the numerous processes introduced in recent years, with extravagant and preposterous claims that have gone far to bring liquid air into disrepute. A serious scientist saw long ago the only really valuable commercial application of oxygen and nitrogen. For many years he devoted himself to adopting his system of liquefying air for this purpose. That his labours have been crowned with success has been proved by the fact that on the Continent the company which controls his patents has already erected a large number of plants, which are in daily operation, giving most satisfactory

results. It is the Linde plant that the British Oxygen Company erected at Westminster and many other great centres.

Briefly expressed, the process consists of liquefying the air completely in the first instance by the self-intensive system. Whilst obtaining almost complete transference of heat from the compressed air entering the apparatus to the liquefied air, the liquid is submitted to a special process of rectification, by means of which oxygen of any degree of purity up to 98 or 99 per cent. can be obtained. The plant is driven by a Diesel engine, which develops some 35 h.p. Air is compressed by three stage compressors, belt-driven. Between each stage of compression the air is restored to normal temperature by passing through coils contained in a cooler, through which water circulates. The system of purification of the air is very complete, all the moisture and carbolic acid being practically eliminated, first in the purifiers containing unslaked lime and calcium chloride, while the final traces of moisture are subsequently removed by freezing in a forecooler, which is employed, partly for this purpose, partly to precool the air before it enters the separators. The lower part of the forecooler is reduced in temperature by a small CO_2 refrigerating machine of the usual type made by the Linde British Refrigerating Company, but the upper part is cooled by the waste nitrogen from the separator.

The interchange is so effective that, before the nitrogen is returned to the atmosphere, it has taken so much heat from the incoming compressed air that it leaves the forecooler only a few degrees below normal temperature. The compressed air, on the other hand, leaves the bottom of the forecooler at a temperature considerably below freezing-point, and then enters the top of the separator, passing downwards to a series of coils, which are so constructed as to be surrounded by both the outgoing cold gases. The bottom of the separator contains liquid air, or, more correctly speaking, liquid oxygen. The compressed air, on its way to the expansion point, is conveyed through the liquid, by which means it is largely condensed. It then passes through the regulating valve, at which point it expands, and is ultimately discharged into the top of an inner central chamber which forms the rectifying column, in which the separation of oxygen and nitrogen is effected, oxygen descending in a liquid state to the bottom of the separator, nitrogen ascending in a gaseous or vaporous condition to the top.

The nitrogen is allowed freely to discharge into the atmosphere through the forecooler, as already explained; the oxygen is allowed to boil off in any desired quantity by the adjustment of a

discharge valve. Both gases, however, on leaving the separator, are kept in intimate contact with the cells conveying the incoming air, so that before leaving the apparatus the heat of the incoming air has been mostly transferred to the gases. The plant is very conveniently arranged, and consists of two separators and two fore-coolers, one of each being worked at a time. In this way continuous working is ensured, for when ice (due to entrapped traces of moisture in the air) has accumulated to such an extent as to cause a stoppage in one separator, the other can be put in operation, whilst the first is allowed to thaw. In practice, freezing is found to occur after six to seven days of continuous work.

The description here given represents the normal working of the plants. But before pure oxygen can be produced the separator has to be cooled down, and a considerable quantity of liquid produced. This operation takes about three hours, during which time the compressed air circulating through the coils is (by the adjustment of the regulating valve) maintained at a pressure of about 2,500 pounds per square inch. Afterwards, when the oxygen is being produced, the pressure is about 800 pounds per square inch, at which pressure it continues to work.

Oxygen obtained from liquid air may contain more or less nitrogen. That obtained by the electrolysis of water might contain a little hydrogen. These two gases are considered as impurities. If hydrogen were present to an appreciable extent, it would have the disadvantage of forming with the oxygen an explosive mixture. It has been demonstrated that in the cutting of iron and steel by the blowpipe cutters, the presence of nitrogen, even in small quantities, has an adverse effect on the quality and rapidity. Oxygen compressed in cylinders is generally delivered containing 96 to 99 per cent. of oxygen; but the commercial guarantee may be as low as 95 per cent. The British Oxygen Company guarantee the quality of their oxygen as 98·5 to 99 per cent., and many experiments carried out by the author confirm this.

Analysis is conducted by acting on a definite volume of gas with a chemical which rapidly absorbs the oxygen and leaves the impurities intact (hydrogen, nitrogen, or carbon dioxide). The quantity of gas absorbed, compared with the original volume, gives the degrees of purity. The analysis is generally done in graduated test-tubes, as a rule of 100 centimetres capacity and graduated 0 to 100. The absorbent liquid takes the place of the oxygen absorbed, so that when the reaction is over it is only necessary to read off the level of the liquid to know the purity of the oxygen.

CHAPTER IV

MANUFACTURE OF HYDROGEN

THESE two gases—oxygen and hydrogen—are now manufactured on very large scales. Hydrogen can be very much more freely obtained than in the past, and will be more used in future for welding purposes. There are very few who are acquainted with oxy-hydrogen as applied to welding at the present time, although it was in extensive use until the advent of calcium carbide in large commercial quantities, which generate the acetylene gas. The latter was employed, in combination with oxygen, for use in the blowpipe for welding, giving a very much higher temperature of 6,000° F. against the oxy-hydrogen flame's 4,000° F.

There are many advantages in using oxy-hydrogen blowpipes. Firstly, the hydrogen is supplied in cylinders, the same as oxygen. Therefore it can practically be used anywhere. There is no wasted gas, no expense in initial outlay for generators or fixing of piping, no messy substance to clear away, as in acetylene generators, the two gases, oxygen and hydrogen, under equal pressures, thus ensuring a constant, steady flame. This blowpipe is also well adapted for the burning of lead and the welding of aluminium, because the heat of temperature is not so high, but is suitable for these metals. However, there is the disadvantage of not being able to get high enough temperature to weld heavy mild steel or cast iron, as the heat is absorbed and there is loss by conductivity. It is practically impossible to weld steel plates exceeding $\frac{1}{16}$ inch thick.

The flame is produced by the mixing of two volumes of hydrogen and one of oxygen. This is the theoretical mixture; but the author found in practice that it required, to maintain a good heat to complete a proper weld, three parts of hydrogen to one of oxygen. Hydrogen and oxygen have strong affinity for each other. Their combination occurs with great explosive violence, the product being water in the form of steam. This steam is, of course, superheated in the hot flame, which process of dissociation involves a consumption of heat, which is abstracted from the flame, hence an oxidising effect on the weld. This can only be avoided by feeding the flame with

an excess of hydrogen (in practice four to five volumes of hydrogen to one of oxygen), whilst, on the other hand, only that amount of heat can be obtained which is disengaged in the combination of the two volumes of hydrogen and one of oxygen. The large excess of hydrogen required to prevent oxidation furnishes in itself one way why welding by means of the hydrogen-oxygen flame is frequently uneconomical. A further reason, however, lies in the fact that the temperature of the flame, in consequence of this excess of hydrogen, is essentially lower than it ought to be. In spite of this, it is found in practice that for thin plate welding the oxy-hydrogen blowpipe has certain advantages. The flame is more diffused than in the case of oxy-acetylene flame, hence less liable to melt through and pierce the metal.

Every student, if he is to become a welder, must have a fair knowledge of all the materials used and their constituents, as also of the gases such as oxygen, hydrogen, and acetylene. Since these gases are usually provided in convenient cylinders for commercial purposes, the users as a rule are not acquainted with their manufacture or with the source of supply. But it is really essential that the users of these gases should be acquainted with the process of manufacturing them. It is probable that the war, which has brought home to many engineers and business men how easily hydrogen and oxygen can be generated, will lead to an increased demand for these gases and to their wider appreciation in industrial processes.

Where both the decomposition products of water, hydrogen, and oxygen can be utilised, electrolytic generation offers advantages over the isolation of hydrogen from water-gas, which is a cheaper method when worked on a really large scale. In the laboratory the electrolysis of water is a very simple matter. The electrodes are placed in acidulated water in a glass cell. Each electrode is surrounded by a hood (an inverted test-tube, *e.g.*, in which the gas evolved collects). Currents of about two volts give one volume of oxygen and two of hydrogen.

The technical electrolyser is not quite so simple as the laboratory cell. The design and construction of automatic apparatus which will continuously yield both gases in a pure condition of 90 per cent. and more, practically without requiring any attendance, have left sufficient scope for the ingenuity of inventors. Glass cells being out of the question, the container has to be adapted to the electrolyte. Water itself is a poor conductor to serve as an electrolyte. Either sulphur acid or caustic, both of about 20 per cent. concentration, are used; but the chemicals are merely to increase the con-

ductivity of the water, which is the electrolyte, and has to be replenished by feeding distilled water into the cells. The impurities of ordinary water, notably chlorine, would tend to corrode the apparatus.

The acid is placed in lead containers, the alkali in iron cells. The reversible decomposition of the water itself would only require 1·23 volts; but the potential applied has to overcome the resistance of the leads and of the electrolyte, and further the polarisation of the electrodes by the gases liberated. Sulphuric acid is a better conductor than alkali, but the supertension of the lead cathode is decidedly higher. Hence, on the whole, the caustic alkali requires a lower decomposition potential. As regards gas purity and, to a certain extent, the efficiency, there is not much to choose between the acid and the alkali processes, though the number of kilowatt hours required for the liberation of 35 cubic feet of the two gases varies from 6 down to about 3·5, at volts ranging from 3·6 down to 2·3. But in all these figures the decimals become important, and there are features justifying a careful selection of a type of electrolyser.

The general preference is for alkali cells. In the Schoop acid electrolysers, the two groups of electrodes, anodes, and twice as many cathodes, are all lead tubes, open below to let the acid act on the lead wires in the tube. Each tube is insulated by a refractory hood. The groups are coupled in parallel.

In the Garute alkali electrolyser, vertical diaphragms of iron separate the iron tank into anode and cathode compartments, the two groups of iron electrodes being again in parallel.

The Schukert electrolyser uses insulating diaphragms and places iron hoods in the different compartments to collect the gases.

The Schmidt cell of the Oerlikon Company is of the filter-press type, and the corrugated iron electrodes are coupled in series. They are, in fact, bipolar, as in some electrolytic copper baths and in bleach cells.

The electrolysers of the Integral Oxygen Company, London, illustrated on p. 20, differ from types mentioned above in so far as each cell is self-contained, in having two electrode units, and, further, as to arrangements made for the regulation of the gas pressure. This is an Integral unit generator. The cells are of the Hayard-Flamand type. The early patents of this cell date back to 1900, but the particulars, the feed and pressure regulation, are later inventions. The battery photograph seems to suggest a filter-press arrangement, but each cell is independent, and the common features

are the water and the gas pipes and the grouping in series. Each cell is independent, each has its own feed and discharge devices, each consists of a thin, rectangular frame of cast iron, to which two cast-iron plates, the electrodes, are bolted, mica insulators being interposed.

The asbestos diaphragm divides the space of the flat cell vertically into two halves, an anode compartment and a cathode compartment. Each compartment communicates through two ports with a gas chamber. The right is the water chamber. Several jars and pipes

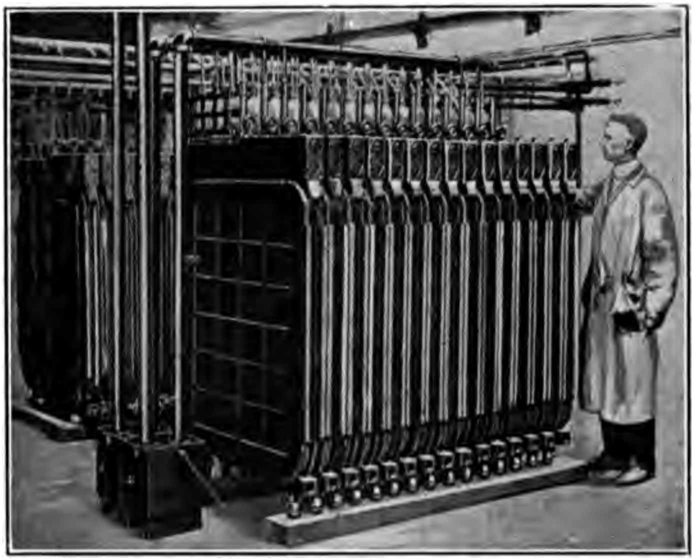


FIG. 8.—4,000-UNIT GENERATORS FOR PRODUCING OXYGEN AND HYDROGEN.

will be seen on the top of the gas chamber. The gas leaves through the two outer glass jars—the hydrogen through the jar on the right, the oxygen through that on the left—and enters the two gas pipes which are in, but not on, the sketch. A third pipe is the distilled-water pipe. This is connected with the central jar through which the cell is originally charged with caustic soda of 20 per cent. The cell discharges a spray of gas and caustic soda; this frothy liquid spreads upon the base plate, which has a raised edge, this ridge preventing the liquid from running back into the port and choking it. It spreads over to the port and there flows back into the cell. Thus a kind of circulation is set up; the gas itself is further deprived of its

moisture by having to force its way through a gas tap in the glass jar, which contains an inverted bell of iron. The liquid is intercepted between this bell and the jar, the top of which is joined to the gas pipe. The cells are worked at a temperature of about 55° C. The guaranteed purity of the gases evolved is oxygen 99 per cent., hydrogen 99·5 per cent. During recent trials at Farnborough the oxygen purity was maintained at 99·8 per cent., which was an exceptionally high figure.

It must be noted that the gases are not purified in any way, but enter the gas holders or cylinders as they leave the glass jars. The average potential is about 2·2 or 2·3 volts per cell, at the normal current of about 600 ampères. Each cell has a rated output of 4·8 cubic feet of oxygen and 9·6 of hydrogen, and gives an average yield of 4 cubic feet of oxygen, and twice as much hydrogen.

CHAPTER V

MANUFACTURE OF CARBIDE

THE manufacture of calcium carbide is carried out on such extensive lines that any student of welding should make himself conversant with its manufacture. Acetylene was discovered by Davy in the chemical laboratory in the year 1836. Many methods of preparing the gas were described by various experimenters, the majority of which are only of academic interest. But it may be mentioned that in 1840 Hare, by heating in an electric arc a black residue obtained by heating a mixture of mercuric cyanide and lime, arrived at a compound which was undoubtedly calcium carbide, although not recognised as such at the time.

The next date of importance is the year 1862, in which the German chemist Woehler (whose name is well known amongst chemists as the discoverer of synthetic urea and other important bodies, including aluminium) obtained "calcium of carbide" decomposed water with formation of calcium hydrate and acetylene. It is hard, really, to say who was the actual discoverer of calcium carbide. It was Moisson, "the king of experimental savants," who published his classic investigations. His results were obtained as factors in a magnificent research, every step in which was logically worked out and verified; a research which will ever stand out as a scientific classic. But the fact remains that he only attained and published the discovery of the direct formation of calcium carbide in the electric furnace to find that his work had been forestalled by a few months by the chance observation of an engineer who, although devoid of chemical knowledge, yet had sufficient acumen to grasp the commercial importance of the discovery. Anyone who, with a mind free from prejudice, reads the evidence on this subject, is forced to the conclusion that the world owes "commercial acetylene" to the Canadian engineer, Willson, and the shrewd business men who supported him.

Moisson obtained crystallised calcium carbide during a systematic and masterly research upon the products of the electric furnace. His first paper described an electric furnace, which he distinctly stated was not an industrial apparatus, but for research purposes

only. His work consisted in the preparation of crystallised metallic oxides such as those of calcium, strontium, barium, magnesium, aluminium, iron, chromium, etc. He then dealt with fusion and volatilisation of some refractory bodies and metals. This was followed by his classical research on the different varieties of carbon and the formation of the diamond. The description of the formation of calcium carbide is included in a study of the carbides, silicides, and the borides. After a brief review dealing with the work of Berthelot, Woehler, and Travers, who in 1893 obtained a mixture containing some carbide, Moisson writes:

" The question had reached this point when, in a note appearing in the *Comptes Rendus de l'Académie des Sciences* on December 12, 1892, I made public for the first time the formation in the electric furnace of a carbide of calcium fusible at a high temperature. This is what I wrote on the subject. If the temperature reaches 3,000° C., even the furnace material, the quicklime, melts and flows like water. At this temperature the carbon quickly reduces the oxide of calcium (lime), the metal itself is liberated in abundance; it unites readily with the carbon of the electrodes to form a carbide of calcium, liquid at a red heat, which is easy to recover. Following this research, I presented to the Académie des Sciences a note of carbide of calcium on March 5, 1894, another note of carbides of barium and strontium on March 9, 1894. In this work I showed that in a high temperature of the electric furnace there exists only one compound of carbon and calcium. This compound was crystalline; I established its formula by analysis, and in the study of its properties I made it clear that the bodies decompose in water, liberating the gas acetylene absolutely pure."

This was the starting-point of the acetylene industry.

At the end of a patent, No. 492,377, U.S.A., on the preparation of aluminium bronze, M. Thos. Willson made an allusion to an interminate carbide of calcium as well as to a great number of other bodies, elements or compounds, but did not give an analysis of the two compounds obtained, nor even mentioned that this product decomposes cold water with liberation of any gas whatever. He also avoided, with the greatest care, that " bath of fusion " brought metallic calcium.

Moisson prepared his carbide by making an intimate mixture of 120 grammes of lime from marble, and 70 grammes of carbonised sugar, heating for fifteen minutes in a crucible in the electric furnace with a current of 350 ampères and 70 volts. He used a slight excess of lime to counteract the carbon obtained from the crucible. He

noted that if any impure lime was used, containing sulphates, phosphates, or silica, these impurities would be found in the acetylene liberated from the carbide. Moisson carried out a number of experiments with impure materials and analysed the gas obtained; also studied the physical qualities of the carbide, the gas yield as well as its chemical properties and that of acetylene. It is interesting to note that he states that " pure and dry " nitrogen does not react with carbide even at 1,200° C. Had he continued this experiment to a higher temperature he would have probably been the discoverer of cyanamide.

Whatever the facts of the case may be, Moisson's systematic and scientific research work and the practical results obtained place his name for ever in an unassailable position in the history of the industry. From the time when Moisson and Willson published their investigations, the accepted equation for the production of calcium of carbide in the electric furnace from carbonaceous matter and lime has always been—

$$CaO + 3C = CaC_2 + CO.$$

This final result may be approximately the production of two compounds, CaC_2 and CO; but the reaction, or rather, reactions which take place before the final stage is reached certainly appear to be far more complex. The conversion of the raw material into carbide appears to take place in steps.

In the past, every person who had cheap water-power available believed that he had the Alpha and Omega for making cheap carbide, even if there was no limestone or carbon within hundreds of miles. To equip a modern factory, a very large capital is required, and a suitable site, where cheap water-power is available, near to limestone, coal, and coke. The power for electric energy, in the case of every carbide factory in existence, is supplied from a hydro-electric station, where the prime mover, or force, is falling water—in other words, a waterfall. This falling water passes through turbines or Pelton wheels. The type of turbine is decided by the head or volume of water available. These turbines drive dynamos or electric generators; some of these generators are used in the electric furnaces for the melting of the carbon and the lime for producing the carbide of calcium.

An electric carbide furnace as a rule consists simply of a steel case or box, or a steel-framed case or box lined inside with suitable refractory material, having a tapping hole very similar to a tapping hole in an iron-furnace or cupola. In some of the furnaces electrodes are fixed in the bottom of the furnace; in others the electrodes are

suspended from the top. Each of the electrodes is held in various kinds of holders, which are connected to busbars. The electrodes are made of carbon. The materials used in the manufacture of carbide of calcium are primarily—

(*a*) Carbon for the charge in the form of coal or coke,
(*b*) Carbon for the electrodes,
(*c*) Lime.

Coal.—Only one form of coal, *anthracite*, has up to the present given anything like satisfactory results. An anthracite coal containing not more than 4 per cent. of ash and not more than 0·040 per cent. of phosphorus will serve admirably in a modern furnace.

Limestone.—Mountain limestone is the stone composing the limestone ranges known to most of us. The best stone is found in the Buxton and Settle Hills districts. There is also oolitic limestone (so called because of the resemblance to a mass of fish roe), made up of small rounded grains of carbonate of lime. Chalk is fine-grained limestone, consisting of finely commuted shells. Magnesia limestone is a limestone mixed with more or less magnesia. This is very suitable for carbide-making. The principal impurities present in limestone used for carbide-making are magnesia, alumina, silica, iron oxide, sulphur, and alkalies. The maximum quantities of impurities permissible in good limestone for carbide should be about 0·50 per cent. of magnesia (MgO), 0·50 per cent. of alumina and iron oxide, 0·01 per cent. of phosphoric acid (P_2O_5), about 1 to 1·2 per cent. of silica (SiO_2), and only traces of sulphur. This corresponds to a stone containing about 97 to 98 per cent. of carbonate of lime.

Carbide, as now made by a first-class factory, yields 310 litres per kilogramme (4·95 feet per pound), and contains, therefore, 89 per cent. of pure carbide, 11 per cent. of impurities. A metric ton of commercial carbide will contain 890 kilogrammes of pure carbide. To produce this 890 kilogrammes of pure carbide in a metric ton, based on the lime of 96 per cent. purity, coke with 6 per cent. of ash, the following will be theoretically the quantities of raw materials for a metric ton of carbide—

$$\text{Lime} \quad \frac{56}{64} \times \frac{890}{0{\cdot}96} = 811 \text{ kilogrammes.}$$

$$\text{Coke} \quad \frac{36}{64} \times \frac{890}{0{\cdot}96} = 521 \quad ,,$$

$$\text{Total kilogrammes } \underline{\overline{1{,}332}} = 2{,}797 \text{ pounds.}$$

(1 kilogramme = 2·2 pounds.)

Therefore it takes 1,332 kilogrammes of materials to produce 890 kilogrammes of commercial carbide. Carbide is produced in the electric furnace by the fusion of coal approximately 36 parts by weight, lime 56 parts by weight, to a temperature reaching 4,000° C.

Under the enormous temperature of the electric furnace (which is carried by the carbon electrodes) the lime and carbon combine. The liquid carbide which results is tapped from the furnace (the same as the blast furnace or foundry cupola) into receptacles which, when cooled, are transported to the crushing machines, which break them up. Then on the mechanical graders, which separate the various sizes; the carbide is then packed into drums, and the covers are hermetically sealed.

The formula of carbide of calcium is represented by CaC_2; it is made of 62·5 per cent. of calcium.

Use 1·4 pints of water to each pound of carbide in water-to-carbide generators, 5 pints of water in carbide-to-water generators. This should assure full decomposition. Carbide should yield 4·8 cubic feet of acetylene for every pound of carbide placed in the generating chambers. There are various apparatus for testing the carbide on the market. When a sample is tested it must be broken up in a mortar to about ¼-inch mesh, then screened to remove the dust as rapidly as possible, then weighed out in a limited quantity accurately by a chemist's scale. The carbide is then placed in the generating chambers immediately, the water turned on (the height of the bell should be marked before the water is turned on); then, when the generation has ceased, the bell should be marked and then measured with the already provided instruments.

CHAPTER VI

ACETYLENE

ACETYLENE or, as it is scientifically named, "ethine," is a simple hydrocarbon consisting of 24 parts by weight of carbon and 2 parts by weight of hydrogen; its chemical symbol, C_2H_2, meaning it is a compound of two atoms of carbon combined with two atoms of hydrogen. It is a clear, colourless gas, of a specific gravity of 0·92. It is, owing to its synthetic formation, the most pure, at the same time nearly the richest hydrocarbon gas, containing no less than 92·5 per cent. of carbon when perfectly pure and free from water vapour. It has an illuminating value of 50 candle-power per cubic foot.

It has a most unmistakable and penetrating odour. When present in the proportion of only 1 part in 10,000 parts of air it is distinctly perceptible long before there is sufficient gas present to cause explosion. Therefore it can be at once detected, and an explosion prevented. One burner passing 1 cubic foot per hour in a room of 2,500 cubic feet area for a period of nine or ten hours would not be sufficient, with the same quantity of air, to make an explosive mixture. The largest acetylene burners only pass 1 cubic foot per hour, against the 5 cubic feet of coal-gas. It is, therefore, obvious that the prevailing popular belief as to acetylene being more dangerous than coal-gas is a fallacy.

Acetylene and oxygen ignite at a temperature of 400° C. The temperature of combustion is 4,000° C. Acetylene, although practically pure gas, usually contains some impurities in a greater or less proportion, mostly sulphuretted and phosphuretted hydrogen due to the presence of sulphate of calcium, gypsum, and calcium phosphide in the lime, or to the sulphur and phosphorus in the coal and coke. Acetylene is always contaminated with ammonia, formed by the combination of nitrogen derived from the coke with the hydrogen of the water during decomposition of the carbide. That acetylene is a poisonous gas has been proved to be untrue. When pure it is relatively harmless. The range of explosibility is wider in the case of acetylene than of coal-gas. Mixtures having less than 5 and more than 60 per cent. are practically non-explosive.

Acetylene, being an endothermic compound, is liable, when pure, if compressed without at the same time being cooled, to explode spontaneously. Acetylene is soluble in water and many other liquids. It can be liquefied at a pressure of about 325 pounds per square inch and forms a mobile and highly refractory liquid, much lighter than water.

The reactions that occur when carbide and water are brought into contact belong to the class which chemists usually term double decompositions. Calcium carbide is a chemical compound of a metal calcium with carbon containing one chemical "part," or atomic weight, of the former united to two chemical parts of the latter. Its composition is expressed in symbols by CaC_2. Similarly, water is a compound of two chemical parts of hydrogen with one of oxygen, its formula being H_2O. When these two substances are mixed together, the carbon of the calcium carbide leaves the calcium uniting together to form that particular compound of hydrogen and carbon, or hydrocarbon, which is known as acetylene, whose formula is C_2H_2, while the residual calcium and oxygen join together to produce calcium oxide of lime (CaO). Put into the usual form of an equation, the reaction proceeds thus:

$$CaC_2 + H_2O = C_2H_2 + CaO. \quad (1)$$

This equation not only means that calcium carbide and water combine to yield acetylene and lime; it also means that one chemical part of carbide reacts with one chemical part of water to produce one chemical part of acetylene, one of lime. But these four chemical parts, or molecules, which are equal chemically, are not equal in weight, although, according to the common law of chemistry, they each are a fixed proportion one to the other. Hitherto, for the sake of simplicity, the by-product in the preparation of acetylene has been described as calcium oxide, or quicklime. It is, however, one of the characteristics of this body to be hygroscopic, or greedy of moisture, so that if it is brought into the presence of water, either in the form of liquid or vapour, it immediately combines therewith to yield calcium hydroxide, or slaked lime, whose chemical formula is $Ca(OH)_2$. Accordingly, in actual practice, when calcium is mixed with an excess of water, a secondary reaction takes place over and above that indicated by equation (1), the quicklime produced combining with one chemical part or molecule of water, thus:

$$CaO + H_2O = Ca(OH)_2.$$

As these two actions occur simultaneously, it is more usual and more in agreement with the phenomena of an acetylene generator

to represent the decomposition of calcium carbide by the combined equation:

$$CaC_2 + 2H_2O = C_2H_2 + Ca(HO)_2. \quad (2)$$

By the aid of calculations analogous to those employed in the preceding paragraph, it will be noticed that equation (2) states that 1 molecule of calcium carbide, or 64 parts by weight, combines with 2 molecules of water, or 36 parts by weight, to yield 1 molecule, or 26 parts by weight, of acetylene, and 1 molecule, or 74 parts by weight, of calcium hydroxide (slaked lime). Here, again, if more than 36 parts of water are taken for every 64 parts of calcium carbide, the excess of water over these 36 parts is left undecomposed; and in the same fashion, if less than 36 parts of water are taken for every 64 parts of calcium carbide, some of the latter must remain unattacked, whilst, obviously, the amount of acetylene liberated cannot exceed that which corresponds with the quantity of substance suffering complete decomposition. If, for example, the quantity of water present in a generator is more than chemically sufficient to attack all the carbide added, however large or small that excess may be, no more, and, theoretically speaking, no less, acetylene can ever be evolved than 26 parts by weight of gas for every 64 parts by weight of calcium carbide consumed. It is, however, not correct to invert the proposition, and to say that if the carbide is in excess of water added, no more, and, theoretically speaking, no less, acetylene can be involved than 26 parts by weight of gas for every 36 parts of water consumed, as might be gathered from equation (2); because equation (1) shows that 26 parts of acetylene may, on occasion, be produced by the decomposition of 18 parts by weight of water.

From the purely chemical point of view this apparent anomaly is explained by the circumstances that of the 36 parts of water present on the left-hand side of equation (2) only one-half—*i.e.*, 18 parts by weight—are actually decomposed into hydrogen and oxygen, the other 18 parts remaining unattacked, and merely attaching themselves as "water of hydration" to the 56 parts of calcium oxide in equation (1) so as to produce 74 parts calcium hydroxide appearing on right-hand side of equation (2). When the output of gas is measured in terms of the water decomposed, in no commercial apparatus, and, indeed, in no generator which can be imagined fit for actual employment does that output of gas ever approach the quantitative amount, but the volume of the water used, if not actually disappearing, is always vastly in excess of the requirements of equation (2). On the contrary, when the make of gas is measured in the terms of the calcium carbide consumed, a

percentage may be reached of 80, 90, or even 99 per cent. of what is theoretically possible. Inasmuch as calcium carbide is the only costly ingredient in the manufacture of acetylene so long as it is not wasted—so long, that is to say, as nearly the theoretical yield of gas is obtained from it—an acetylene generator is satisfactory or efficient in this particular; and, except for the matter of solubility, the quantity of water consumed is of no importance whatever.

The chemical action between calcium carbide and water is accompanied by a large involution of heat, which, unless due precautions are taken to prevent it, raises the temperature of the substances employed, and of the apparatus containing them, to a serious and often inconvenient extent. This phenomenon is the most important of all in connection with acetylene manufacture, for upon a proper recognition of it, and upon the character of the precautions taken to avoid its numerous evil effects, depend the actual value and capacity for smooth working of an acetylene generator. Just as, by an immutable law of chemistry, a given weight of calcium carbide yields a given weight of acetylene, and by no amount of ingenuity can be made to produce either more or less, so, by an immutable law of physics, the decomposition of a given weight of calcium carbide by water, or the decomposition of a given weight of water by calcium carbide, yields a definite quantity of heat—a quantity of heat which cannot be reduced or increased by any artifice whatever.

A very little experiment will show that a notable quantity of heat is set free when calcium carbide is brought into contact with water, and, by arranging the details of the apparatus in a suitable manner, the quantity of heat manifested may be measured with considerable accuracy. A lengthy description of the method performing this operation is unnecessary. It is sufficient to say that the heat is estimated by decomposing a known weight of carbide by means of water in a small vessel surrounded on all sides by a carefully jacketed receptacle full of water, provided with a sensitive thermometer. The quantity of the water contained in the outer vessel being known, and its temperature having been noted before the reaction commences, an observation of the thermometer after the decomposition is finished, when the mercury has reached its highest point, gives data which show that the reaction between water and a known weight of calcium carbide produces sufficient in amount to raise a known weight of water through a known thermometric distance; and from these figures the corresponding number of calories may easily be calculated.

It is well to remark that there is scarcely any feature in the generation of acetylene from calcium carbide and water—certainly

no important feature—which introduces into practice principles not already known to chemists and engineers. Once the gas is set free, it ranks simply as an inflammable, moisture-laden, somewhat impure, illuminating and heat-giving gas, which has to be dried, purified, stored, and led to the place of combustion. It is in this respect precisely analogous to coal-gas. Even the actual generation is only an exothermic, or heat-producing, reaction between a solid and a liquid, in which the rise in temperature and pressure must be prevented as far as possible. Accordingly, there is no fundamental or indispensable portion of an acetylene apparatus which lends itself to the protection of the patent laws.

Treatment of Acetylene after Generation.—The calcium carbide manufactured to-day, even the best obtainable, is by no means a chemically pure substance. It contains a large number of impurities, or foreign bodies, some of which evolve gas on treatment with water. To a certain extent, this statement will always remain true in the future, for in order to make absolutely pure carbide it would be necessary for the manufacturer to obtain and employ perfectly pure lime, carbon, and electrodes in the electric furnace which did not suffer attack during the passage of a powerful current, or he would have to devise some process simultaneously or subsequently removing from his carbide those impurities which were derived from his impure raw material, or from the walls of his furnace. Besides the impurities thus inevitably arising from the calcium carbide decomposed, however, other impurities may be added to the acetylene by the action of a badly designed generator, or one working on a wrong system of construction. Therefore it may be said at once that the crude gas coming from the generating plant is seldom fit for immediate consumption. It must invariably be submitted to a rigorous method of chemical purification.

Combining together what may be termed the carbide impurities and the generator impurities, in crude acetylene the foreign bodies are partly gaseous, partly liquid, partly solid. They may render the gas dangerous from the point of view of possible explosion. They may be harmful to health if inhaled, injurious to the fittings and decorations of rooms, objectional at the blowpipe orifices by determining or assisting the formation of the solid growths which distort the flame and so reduce its power; they may give trouble in the pipes by condensing from the state of vapour in the bends and dips, or by depositing, if they are already solid, in angles, etc., and so causing stoppages.

It will be apparent without argument that a proper system of

purification is one that is competent to remove the carbide impurities from acetylene, as far as removal is desirable or necessary. It should not be necessary to extract generator impurities, because the proper way to deal with them is to prevent their formation. Vapour of water almost always accompanies acetylene from the generator, this being due to the fact that in a generator where the carbide is in excess the temperature tends to rise until part of the water is vaporised and carried out of the decomposing chamber before it has an opportunity of reacting with the excess of carbide. In large plants the extraction of the moisture may take place in two stages. The gas from the generator is generally passed slowly through a condenser, although in smaller generators it is often quite suitable for the gas to pass through the water of the generator in order to remove the soluble impurities. The generator impurities present in the crudest acetylene consist of hydrogen and nitrogen—*i.e.*, the main constituents of air; the various gases—liquid and semisolid bodies—which are produced by the polymerising and decomposing action of heat upon the carbide, water, and acetylene in the apparatus; and, wherever the carbide is in excess in the generator, some lime in the form of very fine dust. This lime dust, which is calcium oxide or hydroxide, carried forward by the stream of gas in extremely fine subdivision, is liable to be produced whenever water acts rapidly upon an excess of calcium carbide. It occasionally appears in the alternative form of froth in the pipes leading directly from the generating chamber. This froth is hard to break up.

A purifying system must remove generator impurities, unless the generator is so perfect that it does not give them off. With the exception of the gases which are permanent at atmospheric pressure —hydrogen, carbon monoxide, nitrogen, and oxygen—which, once produced, must remain in the acetylene, extraction of these impurities is quite simple. The dust or froth of lime will be removed in the washer where the acetylene bubbles through water. The dust itself can be extracted by merely filtering the gas through cotton-wool, felt, or the like. The least volatile liquid impurities can be removed partly in the condenser, partly in the washer, partly by a mechanical dry-scrubbing action of the solid purifying materials in the chemical purifier. To some extent the more volatile liquid bodies may be removed similarly.

Carbide Impurities.—Neglecting very minute amounts of carbon monoxide and hydrogen as being insignificant from the practical point of view, the carbide impurities of the gas fall into three main categories: those containing sulphur, those containing silicon, those

containing gaseous ammonia. The phosphorus in the gas becomes calcium phosphide in the calcium carbide which is attacked by water, and yields phosphuretted hydrogen (or phosphine). The calcium phosphide, in its turn, is produced in the electric furnace by the action of the coke upon the phosphorus in phosphatic lime. The sulphur in the gas comes from aluminium sulphide in the carbide. Even in the absence of aluminium compounds, sulphuretted hydrogen may be found in the gas of an acetylene generator. In the gas itself the ammonia exists as such, the phosphorus mainly as phosphine. The sulphur is present partly as sulphuretted hydrogen, partly as organic compounds analogous, in all probability, to those of phosphorus. Ammonia and sulphuretted hydrogen are both soluble in water, the latter more particularly in limewater of an active acetylene generator, while all other bodies referred to are completely insoluble. Therefore a proper washing of crude gas in the water should suffice to remove all ammonia and sulphuretted hydrogen from the acetylene.

When acetylene was first introduced on commercial lines, the generator manufacturers began to attack the problem of purification in a perfectly empirical way, either employing some purely mechanical scrubber, filled with moist or dry porous material, or perhaps coke or the like, wetted with dilute acid. At first sight it might appear that the methods of treating coal-gas would suit acetylene, as the latter contains two of the impurities, sulphuretted hydrogen and ammonia. Setting on one side, as worthy of attention, certain compositions offered as acetylene-purifying materials, whose constitutions have not been developed, and whose action has not been certified by respectable authority, there are now three principal chemical reagents in regular use. These are chromic acid, cuprous chloride, and bleaching powder. Chromic acid is employed in the form of solution acidified with acetic acid. In order to obtain the advantages attendant upon the use of a solid purifying material, this is absorbed in that highly porous and inert silica known as infusorial earth or "kieselgühr." This substance was first recommended by Ullmann, and is termed commercially "heratol." As sold, it contains about 136 grammes of chromic acid per kilogramme.

Cuprous chloride is used as a solution in strong hydrochloric acid, mixed ferric chloride, similarly absorbed in "kieselg hr." From the name of its proposer, this composition is called "frankoline." It will be observed that both heratol and frankoline are powerfully acid, whence it follows that they are capable of extracting any ammonia that may enter the purifier. But this material

should be in an earthen vessel. Heratol changes somewhat in colour as it becomes spent, its original tint, due to the chromic acid, altering to a dirty green, characteristic of the reduced state of the chromium.

Frankoline has been asserted to be capable of regeneration or revivification—*i.e.*, when spent it may be rendered fit for further service by being exposed to the air for a time, as is done with gas oxide.

Of all these materials, heratol is the completest purifier of acetylene, removing phosphorus and sulphur most rapidly and thoroughly, and not appreciably diminishing in speed or efficiency until its chromic acid is practically used up. On the other hand, heratol does not act on pure acetylene, so that purifiers containing it should be small in size, and frequently recharged.

Frankoline is very efficacious as regards phosphorus, but it does not extract sulphur. The purifying materials mentioned may be valued by their price, proper allowance being made for the quantity of gas purified per unit weight of substance taken. The annexed table shows approximately:

(1) The number of litres of gas purified by 1 kilogramme of the substance, and

(2) The number of cubic feet purified per pound.

	Litres per Kilogramme.	*Cubic Feet per Pound.*
Heratol	5,000	80
Frankoline	9,000	144
Puratylene	1,000	156

Opinions differ as to the maximum volume of acetylene which a certain variety of purifying material will treat. If 1 pound of a certain substance will purify 200 cubic feet of normal crude acetylene, that weight is sufficient to treat the gas evolved from 40 pounds of carbide, but it will only do so provided it is so disposed in the purifier that the gas does not pass through it at too high a speed that it is capable of complete exhaustion.

Purifiers charged with heratol are stated, however, to admit of a more rapid flow of the gas than is the case with other materials. The ordinary allowance is 1 pound of heratol for every cubic foot per hour of acetylene passing, with a minimum charge of 7 pounds of the material. As the quantity of the material is increased, the flow of the gas per hour may be proportionately increased—*e.g.*, a purifier charged with 133 pounds of heratol should purify 144 cubic feet of acetylene per hour.

CHAPTER VII

OXYGEN CYLINDERS

THE rapid and extensive developments of the oxy-acetylene process in recent times has led, of course, to a corresponding growth in the handling and use of oxygen cylinders. If simple and indispensable precautions are followed in manipulating the cylinders and utilising the gas they contain, no real danger is present; but many welders are entirely ignorant of the care required, and the author proposes therefore to mention a few principal points in the construction and handling of these cylinders.

The manufacture, transport, and utilisation of cylinders of compressed gases were investigated by a Government Committee in 1895, and, although their recommendations have not been converted into law, they form the basis for the manufacture of cylinders and the regulation of the gas-cylinder trade. The oxygen cylinders usually employed in oxy-acetylene welding contain from 100 to 200 cubic feet of gas under a pressure of 120 atmospheres, or 1,800 pounds per square inch. The cylinders containing 100 cubic feet are most used, the approximate dimensions of this size being 7 inches diameter and 49 inches over-all length, including valve. The cylinder weighs approximately 1 cwt. The majority of the cylinders are made of seamless steel, and the method of manufacture is of interest. A flat steel slab, about $\frac{3}{4}$ inch thick, is raised to a red heat, and subjected to three hot drawing-through processes. The cylinder is next annealed, and then pickled in acid to remove the scale. After this it is subjected to about six cold drawings, so as to produce the right shape, length, and thickness. The bottom of the cylinder is hemispherical and the open end is swaged down, after previously upsetting the end of the tube so as to form the neck, which, in turn, is screwed to receive the cylinder's valve.

After manufacture, the cylinders are annealed by the manufacturers, and reannealed, valved, and tested by the compressing firm. The cylinders are reannealed every third or fourth year, and retested every one or two years. They are stamped on the neck, so that at any time in their history they can be traced. The most important marks are the annealing and test-mark, giving the date

of the last testing and annealing. A useful mark on the cylinder is that of its capacity or internal volume. A foot is sometimes shrunk on the base of the cylinder. This enables it to be placed in an upright position, and avoids sudden shocks in manipulation. Sectional views through typical oxygen cylinders are shown in Fig. 9. The cap is shown separately.

With regard to the testing of cylinders, ordinary tensile, elongation, and bending tests can only be carried out on finished cylinders by destroying them. It is useful to carry out tests to destruction on about 2 per cent. of the cylinders made at one time to any given specification. Tests for cylinders which are to be put into use are of two kinds:

(1) *The Hydraulic Test.*—The cylinder is subjected to an hydraulic pressure, usually about double the intended working pressure. If a cylinder stands this test, it should be perfectly safe for the working pressure. The hydraulic test gives no information as to whether the cylinder is annealed or not or whether the steel is ductile.

(2) *The Stretch Test.*—It being necessary to examine whether the cylinder has permanently stretched during the hydraulic test, compressing firms have introduced an easily applied and sensitive test called the stretch test. During the hydraulic test the cylinder is placed in a vessel, which forms a water-jacket. A pipe and glass tube communicate with this jacket. If there is any expansion of the cylinder during the hydraulic test water is driven out of the jacket and rises in the glass tube. Oxygen cylinders always contain a certain amount of water which it is impossible to eliminate, and which accumulates during successive fillings, finally occupying several cubic inches. It is therefore necessary carefully to drive out the water contained in a full cylinder before screwing the pressure-reducing valve in position. In this manner the life of the cylinder is increased, and the difficulties encountered when using large quantities of oxygen (as, for example, in cutting) are removed or reduced.

Cylinders of compressed oxygen can be manipulated without any very special precautions. For use they are placed, according to shape, upright or lying down. Carefully avoid letting them fall. Such accidents do not affect cylinders, but may injure the welders, and in many cases damage the reducing valve. The cock or valve is the delicate part of the cylinder. The welder has only, in theory, to open and close the valve at the beginning and the end of the work. This operation, so simple in itself, requires certain precautions. Often on the arrival of the cylinder the valve is hard to

open. The operator should make sure of its working before placing the reducing valve in position, so that any powdered oxide or other dust is blown away. The oxygen on escaping into the air produces a violent hissing. The valve should be opened and closed alternately two or three times. The slightest escape can be detected by the ear. The reducing valve should now be fixed, care being taken to see that the screw on the valve is put in square to the thread of the cylinder, so as to avoid damaging the thread. Screw down tightly with the spanner supplied with the cylinder. Then open the tap on the reducing valve where the rubber pipe fits on, and turn on gently the gas at the cylinder tap, and test if there is any leakage at the cylinder or valve. If there is an escape, which may be shown by the pointer on the gauge rising after the valve of the cylinder has been closed, try to screw the valve tighter without overdoing it, because it will be difficult to reopen after. If the leak still continues, remove the reducing valve, and open the cylinder valve briskly two or three times.

No grease, oil, soap, or any fatty matter must be used, as oxygen under pressure has an oxidising action on all these articles. This causes heat to be produced, which may start combustion, and the conflagration may spread to the ebonite parts of the valve and destroy them. The oxygen then escapes in large quantities from the cylinder, thus tending to produce a brisk combustion by contact with a lighted body. The results may be serious. In case the leak is considerable and it is possible to stop it by ordinary methods, the cylinder should be returned to the manufacturers, with a label attached, "Valve faulty," so that the manufacturers can proceed to repair it before refilling.

There are cases of freezing of the reducing valve by the solidification of water-vapour. Particular warning must be given against melting the ice by heating with the flame of the blowpipe. This is a bad practice, and may lead to accidents. The only thing is to use warm water. In order to avoid excessive expansion of the gas, and the resulting increase in pressure, the cylinders should always be kept away from a warm place. Avoid placing them in the sun or near fires. After emptying, the cylinders should be immediately returned to the company to be refilled. They generally belong to the manufacturers, but one can purchase one's own. Oxygen cylinders are carried on the railways at class 2 rates by goods train, and empties returned at reduced rates. All sent by rail must be fitted with covers, as specified by the Railway Clearing House.

Although much literature on oxy-acetylene welding and cutting has appeared in recent years, there has not been any of a general character in which concise and comprehensive regulations have been given to blowpipe operators.

One frequently comes across cases of trained and efficient welders who are incurring daily risks at their work simply because many important precautions and regulations are unknown to them. It is safe to say far more welding accidents occur through ignorance than through wilful neglect of ordinary safeguards. Only a very small proportion of operators have had the advantage of training at a welding school. No opportunity should be lost of placing regulations bearing on their own security before the large number of men and women operators now employed throughout the country. I append, therefore, the necessary regulations, and I impress on all operators to carry them out for the safeguarding of themselves and others.

Regulations, Precautions, and Safeguards.

(1) In placing contracts for oxygen supplies, a guarantee from the supplier should be obtained, to the effect that oxygen will only be delivered in cylinders which have been made, annealed, tested, and filled strictly in accordance with the recommendations of the British Government Departmental Committee of 1896.

The British railways and all the responsible road and water carriers require these conditions to be complied with.

(2) A guarantee should be also obtained to the effect that the oxygen supplied will be not less than 98·5 per cent. quality.

(3) See that all cylinders supplied with oxygen are painted black and fitted with right-hand valves; never attempt to alter the colour of the cylinder or the screwed thread of the valve connections.

(4) See that cylinders are not exposed to excessive heat.

(5) Oxygen cylinders should not be exposed to temperature exceeding 1,000° F.

(6) Take care not to lay hot welded or cut material on or alongside oxygen cylinders; and great care must be taken never to allow the blowpipe flame or the heat from the same to impinge on the oxygen cylinder.

(7) Carefully avoid the use of oil or grease, or lubricant in any form, upon the cylinder valves or fittings, and keep same dry and free from grit.

(8) Never use keys of long leverage to close cylinder valve; they give under power, which is injurious to the valves, and fre-

quently results in broken spindles. If the valve leaks when closed with ordinary lever key, it is often due to grit. To remove this, open the valve slowly, and then close it sharply.

(9) After disconnecting a cylinder before it is empty, it is desirable to test for leakage by pouring some water into the valve socket. If no bubbles appear in the water, it proves that the valve is gas-tight. The valve gland can be tested in the same way at any time that the valve is open, and a regulator attached, by pouring water into the recessed part of the gland-nut round the spindle. The gland-nut must be tightened up if necessary to prevent leakage.

(10) See that all socket and nipple ends are in good order and free from grit before fixing regulators or other fittings by screwing up the fly-nut "hand tight."

(11) Never open the cylinder valve suddenly when the regulator is fixed. The valve should be opened by tapping the key gently with the hand.

(12) Store cylinders under cover in an outhouse, or in a portion of the premises most remote from any source of fire risk. Avoid as much as possible exposing cylinders to conditions which promote oxidisation, and return empty cylinders to the oxygen factory as quickly as possible. Cylinders should be returned with a label bearing the customer's name, so that they may be identified and credited to him in the oxygen factory.

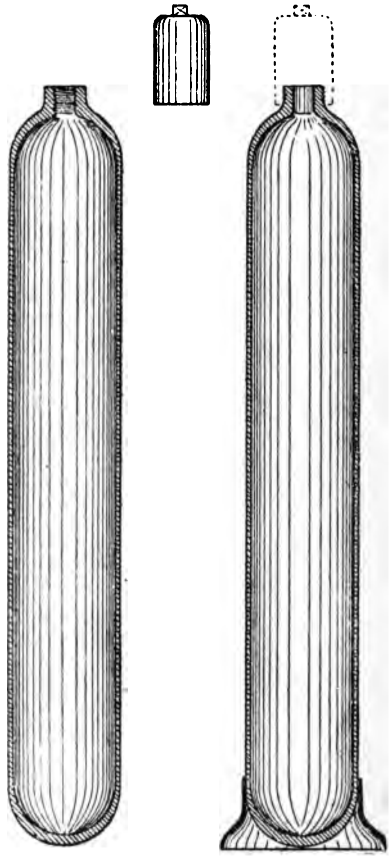


FIG. 9.—SECTION OF AN OXYGEN CYLINDER.

CHAPTER VIII

ACETYLENE GENERATORS

General Construction.—Acetylene generators may be divided into several classes. For the purpose of description three types will be taken—namely, water-to-carbide, carbide-to-water, and the dipping or contact generators. We will describe each one by itself, and state the advantages and disadvantages as they arise.

Most people, when taking up oxy-acetylene welding, decide to purchase a small portable generator. This is a mistake. Such a generator is only intended for occasional use. It frequently happens, therefore, that the purchaser finds after a few weeks that the generator is not large enough, and he has to purchase a larger one. It is very much better to have a large one at first. The first cost may be higher, but the advantages are many, and the saving in gas would pay for the extra cost in a few months.

Generators should be well designed by competent men who have had years of experience, and everything should be carefully thought out and well constructed, somewhat on the following lines:

(1) Generating casing should be made of strong steel sheets, and, after manufacture, galvanised.

(2) The tubes and fittings all galvanised.

(3) Two or more generating chambers.

(4) Generator capable of recharging while working.

(5) Quite automatic.

(6) Capable of taking any over generation.

(7) Washer to absorb the ammonia and sulphurous acid.

(8) Purifier with chemical composition for the removal of phosphorus and other impurities.

(9) Large outlet and inlet tubes, so as not to throttle the gas.

(10) No copper should be used on any part of the generator.

The production of acetylene by the action of water on calcium of carbide is, chemically, one of the simplest of reactions. But in practice it is not so simple. The two chief difficulties in the production of acetylene are heating and excess production. Water consists of hydrogen and oxygen, the dissociation of which takes

place with the absorption of heat. On the other hand, the oxygen liberated combines with calcium carbide and produces the action more heat than is absorbed by the above reaction. The heat liberated is 226 calories or 900 B.T.U. per pound of carbide—that is to say, 1 pound of carbide would raise 1 gallon of water from 0° to 50° C. No device or arrangement can alter this amount of heat liberated; but the temperature of the mass altered will not go beyond the temperature of boiling water. This result is caused in two ways: (1) The water vaporises and acts with the carbide, thus supplementing the heat of decomposition; (2) under the influence of heat the lime gives up the water, reaction continues, and if there is no external cooling the temperature rises. The generation of acetylene at a high temperature is detrimental, and causes polymerisation. This is one reason why manufacturers often put the generating chambers inside the tanks, so as to have the water all round them, and also to have the outlet pipes from the generating chambers turned down from the top, so that the gas is passed through the water cooled and washed.

Polymerisation, as stated previously, takes place owing to too rapid generation, which results in excessive heat to a temperature of 130° F. and causes the lime or spent carbide to turn yellow in the carbide trays, being in the form of a tarry substance.

Carbide gives up sulphide on the action of heat; and the water decomposes into hydrogen sulphide and organic sulphur compounds, which are very detrimental to acetylene. The unpleasant odours of sulphur dioxide are given off on the heating of the gas.

No generator produces the proper proportion of gas consumed. The production, therefore, is either in excess or deficient. Production being in advance, the sudden stoppage of consumption cannot possibly correspond to the above arrest of the reaction.

It is important to note that any particular generator-heating and after-generation are in direct relation to the delivery. It is therefore impossible to formulate rules on this point without taking into account the delivery. The heating should never exceed a temperature of 130° C. The generator bell should be large enough to take all the after-generation in the case of stoppage. A well-designed and constructed generator needs the minimum of attention. It is entirely automatic, only gives gas as required, is strong, and will last for a number of years.

The characteristic point in every generator for welding is its flexibility. It should adapt itself to fluctuating employment—that is, should rise to the maximum and minimum yield without

delay, without heating, without jerks. This refers to automatic generators only.

Non-automatic generators are usually of large dimensions, in which the gas is made in large quantities in advance and stored in a gasometer of from 50 to 500 cubic feet. This method is the most practical, most sure, and most economical by a long way, but the initial cost is high.

FIG. 10.—10-CWT. CARBIDE-TO-WATER GENERATOR.

Fig. 10 is a photograph of a large generating plant, comprising generator, condenser, washer, gasometer, and purifier. It is worked on the usual principle.

Figs. 11 and 12 are carbide-to-water type generators, medium-pressure type, which makes it possible for the storage of the generated gas, with its accompanying advantage of absolute volumetric control. The gasometer obviates the variation of gas

pressure that is inherent in the pressure generator. No regulating or reducing device is necessary, as the acetylene is generated at the pressure required for use. The possibility of loss of gas through leakage in the line and connections is practically eliminated with the low-pressure system. The gas bell provides storage for gas and effectively guards against the loss due to after-generation inherent in other systems.

Control of the feed mechanism is accomplished through the rise and fall of the gas bell, and with absolute gas-pressure. The movement of the gas bell gives a dual motor control—first, through a brake; second, through a position jaw clutch. Special provision is made for shutting off the motor feed when the gas bell is in its lowest position.

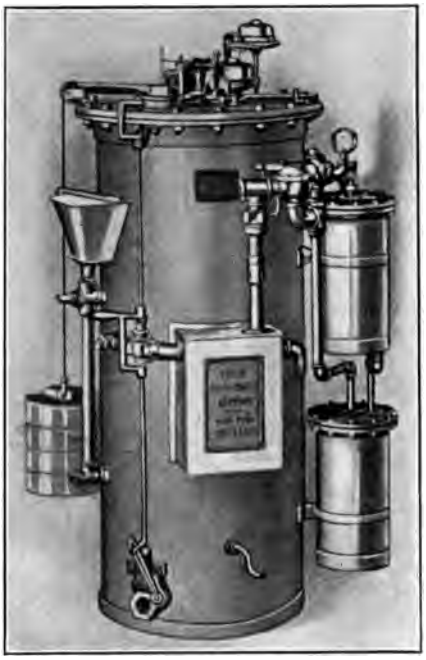


FIG. 11.—50 POUNDS CARBIDE CAPACITY, USING $1\frac{1}{4}$ POUNDS CARBIDE.
Height, 62 inches; diameter, 24 inches; weight, 450 pounds.

Operation of the generator is effected by a small but efficient weight-driven motor, which automatically starts and stops to supply the amount of gas being used. The motor weights always lower approximately the same distance for each pound of carbide used, and constitutes a reliable indication of the amount of carbide remaining in the machine at any time. By the use of positive forced feed, it is impossible for more than the proper quantity of carbide to be fed in the water. In securing cool, and hence efficient, generation, it is necessary to have not less than 1 gallon of water capacity per pound of carbide charge. It is impossible for the temperature of the gas to rise above the boiling-point of water, the acetylene bubbling through the water, free from some of the impurities. By the time the gas is ready to leave the surface outlet its temperature does not exceed that

of the air by more than a few degrees. These conditions permit a yield of pure gas.

A complete and efficient system of interlocking safety devices prevents mistakes in operation due to carelessness or forgetfulness when charging the generator. The hydraulic back-pressure valve is of unique design. With three distinct water seals, it prevents the possibility of any oxygen entering the generator. The generator is equipped with an agitator that churns the residuum thoroughly, allowing it to flow freely and quickly when the residuum is opened for recharging.

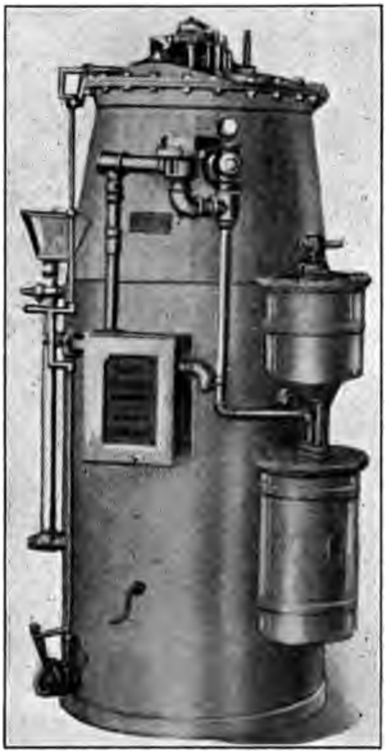


FIG. 12.—100 POUNDS CARBIDE CAPACITY, USING $1\frac{1}{4}$ POUNDS CARBIDE.
Height, 76 inches; diameter, 30 inches; weight, 550 pounds. Known as Davis-Bournonville Pressure Generators.

These generators produce acetylene at a pressure of less than 15 pounds. After the hopper has been filled with carbide ($1\frac{1}{2}$-inch mesh) it is fed to water by means of a revolving disc; surrounding this disc are little plows, or scrapers, that scrape off a certain quantity of the carbide as the disc revolves. The disc is controlled by a governor which is actuated by the gasometer. When the gasometer reaches a predetermined height, the motor is stopped by means of a brake. When the gas bell recedes, the motor is automatically started by releasing the brake. The gas passes from the generator chamber into the gasometer. From there it passes through the filter, where physical impurities and suspended matter are removed, and then through the hydraulic valve, which is a water seal for preventing the reverse flow of gas or air. The gas then passes into the service line. The filter consists of a cylindrical shell within which felt is placed. Perforated plates are placed at the top and

bottom. The gas passes up through the perforations and felt, which collects all dirt, lime, or portions of sludge that would otherwise enter the service line with the gas.

The bell tank is divided by the horizontal partition, the lower portion of the tank forming the seal chamber. The stand pipe projects downward into this chamber, being sealed with water it contains. The function of the seal chamber is to prevent an excessive pressure from accumulating within the apparatus, and precludes the possibility of a backward or reverse pressure entering the generator. Should the pressure of the gas from any cause be increased above the normal pressure, the seal will immediately break. The water will overflow from the seal, filling lip, and release the pressure.

If there should be generated, because of defective or broken apparatus or other reasons, a larger volume of gas than can readily be held by the gas bell, the bell would be forced upward. In order to prevent such an occurrence, there is a stand pipe arranged with a series of blow-off holes. This stand pipe is connected to the vent pipe. Should the stand pipe rise above the level of the water, thus producing a free passage for the gas down the stand pipe through the safety vent pipe to the outside air, as soon as the gas bell was relieved of the excess gas it would lower gradually and the blow-off holes would be again under the water and the flow of gas shut off, thus permitting the generator to resume its normal working condition. The vent valve, the generator filling valve, and the residuum gate are so arranged that they can only be operated in sequence. The opening of the residuum gate therefore allows the gas within the generator to escape to the outside air before any valve or opening from the generator can be made into the room.

CHAPTER IX

OXYGEN REGULATORS

OXYGEN-REDUCING valves are manufactured by various firms, and are of various forms. Some are very reliable and, with care, will last a good number of years. The reducing valves are fixed to the oxygen cylinder by means of a union on the valve. The screws on the union are standardised, as likewise the screws on the top of the cylinder. In the valve of the cylinder there is a faced surface

FIG. 13.—OXYGEN REGULATORS: 1 TWO GAUGES, 1 ONE GAUGE, 1 NO GAUGE.

(concave); on the regulator tip is a convex-faced and ground surface. In fixing the regulator tight in the cylinder, the cylinder spanner should be used, and care taken to see that it is tight; before turning the oxygen on, open the tap of the blowpipe supply, then gently open the valve on the cylinder and see if all is sound. Turn off the blowpipe tap. The regulator must not leak at the cylinder; if it does, turn off the oxygen again and tighten up the union. Try the gas on again. If still leaking, the regulator should be entirely removed, and the oxygen turned on two or three times to blow out any grit or dust that may have accumulated inside the valve.

Then fix the regulator again, and test. This time you will probably be sound.

It is most important to note that there is great danger in getting oil or grease into the union of the reducing valve, because ignition may take place and cause an explosion, doing much damage.

There are three types of regulators; one is shown in Fig. 13. No. 1 has no gauge and, naturally, the cost is less owing to its absence. It is not absolutely necessary to have this gauge. The regulator works

FIG. 14.—DOUBLE CYLINDER CONNECTOR, IN WHICH ONE CAN BE USED WHILE THE OTHER EMPTY ONE CAN BE CHANGED.

quite as well without, but one cannot tell what amount of gas there is in the cylinder; it has got to be used till empty. No. 2 is the same as No. 1, but has a gauge fitted, which registers the gas in the cylinder. No. 3 is for high pressure and is used for cutting purposes. One gauge is for the pressure which is regulated by the tee screw. The other indicates the amount of gas in the cylinder. All oxygen cylinders are painted black, and have a right-hand thread for fitting into the cylinders. These regulators are suitable for every class of work for which oxygen and other compressed gases are used. They automatically deliver gas from the cylinders at any pressure to which they are set. This is very important in welding and for the correct

mixture of the gases. They are substantial in construction, are fitted with a gas expansion device which obviates ignition risks at the valve seat, and are specially recommended for use for all kinds of blowpipe work in connection with oxygen cylinders. The adjustable screwed socket on the side of the regulator No. 1 is graduated in pounds per square inch. The regulator can be set by this to any desired constant pressure.

No. 2 regulator has a high-pressure gauge to register the cylinder pressure; but these pressure gauges, permanently attached to regulators, are a fruitful source of trouble. They soon become inaccurate (particularly the small type so frequently employed), and, being delicate in construction, are liable to injury in workshop handling. The connector illustrated in Fig. 14 is an excellent substitute for the pressure gauge. The regulator is in communication with the cylinders *A* and *B*, one of which can be cut off when not in use. Thus, if the valve of the cylinder *A* and the pipe valve *a* are open, whilst the valve of cylinder *B* and the valve *b* are closed, oxygen flows from cylinder *A* through the regulator till it empties. The valve of cylinder *A* is then closed and that of cylinder *B* opened. Oxygen will then flow to cylinder *B*, whilst the empty cylinder *A* can be removed and replaced by a full one. It will readily be seen that a continuous supply of oxygen can be maintained by the employment of this connector. For prolonged use, regulators with these connectors will be found more convenient and more reliable than those fitted with pressure gauges.

The oxygen should be opened as slowly as possible on to the regulator, and the regulating screw should be fully open. This avoids the heating by quick compression. This is important for the safety of the welder, and preserves the regulator in good working order, because sudden pressure on the diaphragm of the regulator produces derangement and often puts it out of order through the diaphragm splitting. Regulation of the pressure should be secured by the regulating screw until the pressure is that stamped on the blowpipe to be used, and the outlet valve should be full open.

CHAPTER X

REGULATIONS

Regulations, Precautions, and Safeguards for Oxy-Acetylene Welding and Cutting.—There has been much literature on oxy-acetylene welding and cutting in the past, but little has been said as to the precautions necessary. All students and others interested in the oxy-acetylene welding and cutting should study these regulations very closely. One frequently comes across cases of trained and efficient welders who are incurring daily risks at their work simply because many important precautions and regulations are unknown to them. It is safe to say that far more welding accidents occur through ignorance than wilful neglect of ordinary safeguards.

The general regulations which it is necessary to observe in connection with oxygen cylinders have been given above. I now add similar regulations with regard to carbide and to acetylene generators.

Carbide.

(1) Carbide must be stored in iron or steel vessels, hermetically sealed.

(2) The vessels should be kept in a dry and well-ventilated place.

(3) No artificial light capable of igniting inflammable vapour should be employed near these vessels nor in any room where carbide is stored.

(4) Carbide can only be stored without a licence in a quantity not exceeding 28 pounds.

(5) If it is desired to store larger quantities a licence must be obtained from the local authorities.

(6) Carbide should be of a quality to yield not less than 4·8 cubic feet of acetylene per pound.

Fig. 15 shows an airtight carbide chamber; it holds 2 cwt.

Acetylene Generators.

(1) See that the generator is of ample capacity for the continuous production, without heating, of the maximum quantity of acetylene required, and that it complies with all official recommendations.

(2) See that, whether the system employed be automatic or non-automatic, the holder is of sufficient capacity to obviate any loss of gas due to production when the supply to the blowpipe is cut off.

(3) See that the design precludes any appreciable admission of air to the apparatus in the charging with carbide.

(4) See that the limit of pressure in any part of the apparatus does not exceed 250 inches of water.

(5) See that the size of the pipes conveying the gas is proportioned to the maximum rate of generation.

FIG. 15.—AIRTIGHT CARBIDE CHAMBER.

(6) See that it is impossible to seal hermetically the generating apparatus.

(7) See that no copper fittings are employed in connection with the acetylene apparatus.

(8) See that all back-pressure valves are in working order as per regulations.

(9) Charge the apparatus with carbide, if possible, only by day, and do not use small-grained carbide.

(10) Keep the apparatus clean and in good order, and carefully remove all sludge from the generator before recharging with carbide.

(11) Do not use naked lights in the vicinity of the acetylene apparatus.

(12) In frosty weather never use a stove in the vicinity of the acetylene generator. To prevent freezing of water, it is best to employ a steam or hot-water coil.

(13) Employ suitable purifying material and recharge after 110 cubic feet per pound of purifying material have passed through it; test occasionally the acetylene issuing from the blowpipe with a piece of nitrate of silver paper. If this is at all discoloured, it indicates that the purifier requires to be recharged.

(14) See that, in all cases where an acetylene generator is employed, an hydraulic back-pressure valve is employed between it and every blowpipe in use, and that it is properly filled with water. The small drain tap should be opened after filling, any excess of water being drained off. The hydraulic valve must be tested every day in this way before being used.

(15) If, through a back-fire or other cause, water is discharged from the vent pipe, always refill the chamber, and see that the small drip tap is afterwards opened to draw off any excess of water.

(16) The hydraulic back-pressure valve should be dismantled at regular intervals and cleaned out, to make sure that the vent pipe and passages are clear.

CHAPTER XI

BLOWPIPES

Blowpipes intended for the autogenous welding of metals, which employ oxygen and acetylene as the gases, are manufactured instruments, with the same accuracy as a watch; and they must be used as such with care. They are light and easy to handle, and are made with great skill so as to allow the correct proportions of acetylene and oxygen, in specified measured volumes, at a fixed velocity,

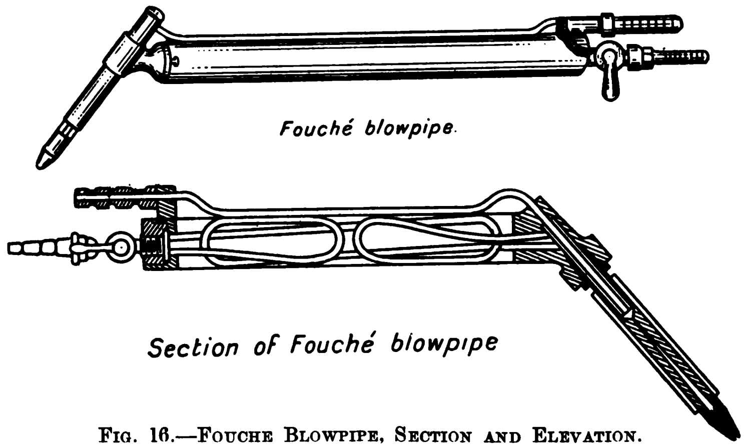


Fig. 16.—Fouche Blowpipe, Section and Elevation.

according to the size of the blowpipe. Their length and weight vary, as does their size, ranging from a consumption of 1·75 of acetylene to 100 cubic feet per hour.

The consumption of acetylene should be about 1 to 1·3 of oxygen. The necessary conditions are much more difficult to realise than they appear to be, especially with blowpipes in which the acetylene is admitted at the pressure of generation, which is about 8 to 12 inches water pressure. A great difficulty is in obtaining the requisite stability. A large number of details merit attention, such as ease of manipulation and ease of taking to pieces and reassembling.

The velocity of propagation is about 330 feet per second in the case of oxygen and acetylene. In order to avoid the striking back of the flame it is necessary that the velocity of the mixture at the exit

FIG. 17.—UNIVERSAL SINGLE TYPE BLOWPIPE WITH HEAD AT SPECIAL ANGLE.

FIG. 18.—UNIVERSAL SINGLE TYPE BLOWPIPE.

should be of the same value, so that it prevents the return of the flame to the interior. The oxygen being under pressure, it is easy to keep this gas constant; but acetylene is not under pressure, and the blowpipes have to be designed to get the amount required to complete the correct mixture for combustion.

Low-pressure blowpipes are designed on the injector principle, and have separate internal jets for the oxygen fixed inside the blowpipe. Such a jet has a very small hole bored in it, the size being determined by the size of the blowpipe for which it is to be used.

FIG. 19.—MULTIPLE TIPS UNIVERSAL BLOWPIPE, SMALL SIZE.

On the outside of this inner oxygen jet is space for the acetylene, which is attached to a tube (usually) which runs along the pipe, where the rubber tubing is fixed. The oxygen under pressure rushes out through the small internal jet, in the place where the acetylene is;

FIG. 20.—MULTIPLE TIPS UNIVERSAL BLOWPIPE, LARGE SIZE.

and the velocity of the oxygen draws the acetylene with it to the mixing chamber and out of the outer nozzle, in the proper proportion required for a good steady flame. Most injector blowpipes are designed on this principle. The intimate mixtures of the gases

should be perfectly accomplished before they escape from the blowpipe. This is difficult to attain, because it is necessary to avoid too much loss of pressure, which would demand an increase in the pressure of oxygen in order to regain the required velocity at the exit. This would be detrimental to the weld.

A blowpipe, which in appearance is such a common article, requires such precision in construction that it can only be undertaken by specialists in the subject. It is essential, indeed, to leave to specialists and experts not only the design and construction but even the repair of blowpipes. Economy and good results in welding depend largely on this. Delivery of oxygen being fixed by the size of the injector orifice, and the power of the blowpipe being invariable in these limits, therefore, in practice, variation of pressure clearly means bad welding. The makers stamp on each size

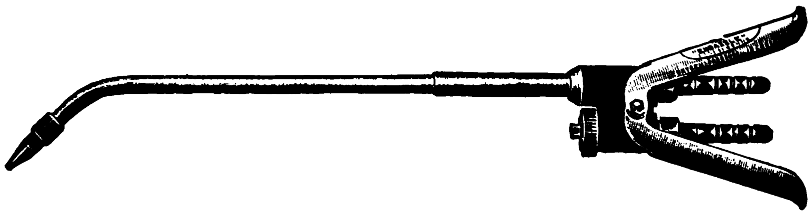


FIG. 21.—ENDAZZLE BLOWPIPE, SINGLE TIP PATTERN.

of blowpipe the correct pressure at which it will work and give the best results. This pressure should not be increased. It is quite a common practice among welders, when their blowpipes are not working well, to increase the oxygen pressure with the idea of getting a better flame. This is a very bad practice indeed, and the weld is usually spoilt. Too much importance cannot be laid on this vital point. Manufacturers who are expert in their line would not stamp a working pressure on their blowpipe if it can be used for higher pressure.

According to the different thicknesses of the metal to be welded, various sizes of blowpipes will be wanted. The pressures and volumes of gases required varying with the size of the welds, it is necessary, therefore, to have blowpipes designed to suit. They range, as has been said, from 1·5 to 100 cubic feet per hour of acetylene gas. There is a great variety of blowpipes at present on the market—some good, some medium, and some bad. All operators should make themselves fully conversant with the various designs and the manufacture of the same. One thing that must be remembered is that the orifice of the nozzle of any blowpipe is proportionate

to the delivery of the injector when using the pressure of oxygen stipulated by the makers. It is essential that it should not be reduced or enlarged. If it were, the gases would not be correctly mixed for the proper combustion for a stable flame. Almost the first blowpipes for low-pressure welding were made by Fouche, a Frenchman. These were well constructed and very

FIG. 22.—ENDAZZLE BLOWPIPE, MULTIPLE TIP PATTERN.

reliable in working. In fact, they are still more reliable than many more modern ones. Their only fault was that they were heavy. Fig. 16 shows one in section and one in elevation.

The "Universal" blowpipes are made by the British Oxygen Company. They are very largely used, and are good blowpipes. They are standardised, and new parts for renewals can easily be got. The

universal blowpipes may have either a fixed or interchangeable head. The two kinds are practically the same in appearance and construction. In the interchangeable set there are loose heads of various sizes, with one handle only. The heads vary in power, and are numbered to correspond with the proper pressure required.

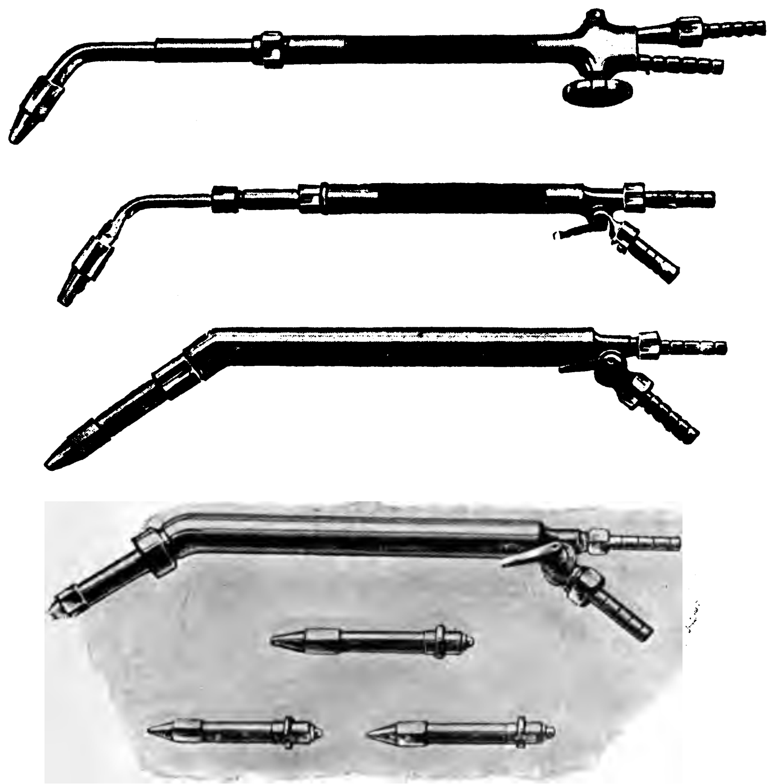


Fig. 23.—Osborne Blowpipes, Four Different Types.

The small size is supplied with seven heads ranging from 2 to 8, and the larger size with four heads, representing 8, 10, 12, 15. These blowpipes are compact and useful.

The blowpipe shown on p. 55, known as the "Endazzle," is extremely light, and has a unique attachment: a pressed-steel hinged cover over the rubber tube connectors. These open right out to allow the rubber tubes to be fixed on the ends of the blowpipe, and

then afterwards close up, which prevents the hands from being burnt should ignition take place at the handle of the blowpipe. This often occurs if the tubing is not a good fit.

The type below (Figs. 24 and 25)—injector heads with tips complete—is made in several sizes for operating on different sections of metals. For greater convenience these blowpipes are made in two models. Each model is supplied complete with directions, and each injector head is of proper proportions to produce the correct mixtures of gases and a flame of perfect stability and correct dimensions according to the work for which it is intended. Model *A* has a range of injector heads—sizes 0 to 4—that is, five different blowpipes (heads only). Model *B* has a range of injector heads—1 to 9—that is, nine different blowpipes (heads only). This covers a good range and will weld anything from $\frac{1}{16}$ inch to 1 inch thick.

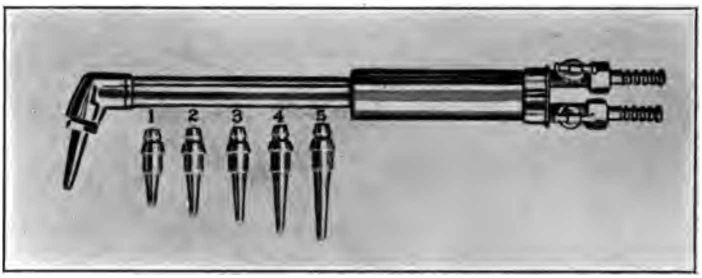


FIG. 24.—SMALL STYLE C WELDING BLOWPIPE, NO. 453.

These blowpipes, known as the Davis-Bournonville type (Figs. 24 and 25), are provided in two standard sizes—large and small—which can be fitted with either square or angle heads (45, 75, or 90 degrees), and straight or angle hose connections; but the standard model is shown here. This blowpipe is very desirable for light and medium sheet metal welding and light repair work, where a light, compact, nicely balanced tool is appreciated. Weight, 18 ounces; length over all, 14 inches. Fitted with five tips—Nos. 1, 2, 3, 4, 5, style 99—using oxygen pressures of 2, 4, 6, 8, and 10 pounds respectively. It is used to advantage on metal $\frac{1}{32}$ to $\frac{5}{16}$ inch thick.

A standard blowpipe for heavy welding, and for general shop work requiring a strong blowpipe. Weight, 2 pounds; length over all, 20 inches. Fitted with five tips—Nos. 6, 7, 8, 9, 10, style 100—using oxygen pressures of 12, 14, 16, 18, and

20 pounds respectively. This blowpipe can be used on metal from $\frac{1}{4}$ inch thick upward.

Consumption of Blowpipes.—Blowpipes of high, medium, and low pressures are constructed so as to give flames of all intensities requisite for the practice of autogenous welding. The power is reckoned according to the hourly consumption of acetylene. Some consume 1·7 to 100 cubic feet of acetylene per hour, or 20 cubic feet, which corresponds to the hourly delivery of acetylene The blowpipe with the lowest consumption uses about 1·5 cubic feet per hour of acetylene. This welds sheet iron or steel up to $\frac{1}{16}$ inch thick; larger blowpipes consume 80 to 100 cubic feet of acetylene per hour, and these weld 1-inch thick material.

In dealing with the consumption of acetylene, it is as well that we should deal with the oxygen at the same time. Theoretically

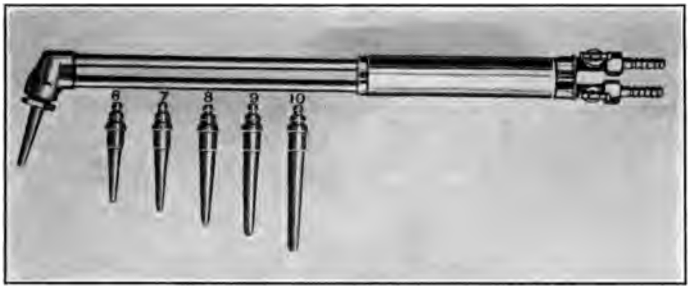


FIG. 25.—LARGE STYLE C WELDING BLOWPIPE, NO. 146.

we know that to get a correct mixture and a neutral flame with a small white cone the gases must be mixed in equal proportions—that is, 1 volume of oxygen, 1 volume of acetylene, when measured under normal temperature. Blowpipes for the high and medium pressures obtain this result by using the two gases under equal pressures, direct from the two cylinders—oxygen and acetylene. It is nearly approached in blowpipes in the medium-pressure system; but it cannot be reached in the low-pressure system.

It is general, in ordinary works practice, to use 1 of acetylene to 1·3 of oxygen; it is only in well-designed blowpipes, working under normal conditions, well-regulated flame, without apparent excess of either oxygen or acetylene, and an expert welder, that these results are obtained. But low-pressure blowpipes give trouble if they are not well taken care of to prevent their getting knocked about. Also there are the difficulties with the regular supply of acetylene

and the constant pressure. The oxygen being under pressure, it is difficult to mix the acetylene in absolutely accurate quantities in order to give it sufficient velocity.

There is evidently an energetic mixing of the two gases, but the contact is not molecule to molecule, and the stream lines of oxygen or acetylene can escape at the nozzle without being mixed. One can test this in different ways—for example, by contracting the exit tube of the mixing chamber, or by increasing the pressure of the oxygen. In both cases the proportion of oxygen to acetylene is raised considerably. From this it is apparent that blowpipes for low pressure use least oxygen when the admission pressure of oxygen is least, and this arrangement for obtaining a mixture of the two gases is the best. In some blowpipes the oxygen pressure to be used corresponds with the arrangement of the mixing chamber. Change of section and abrupt bending produce a loss of pressure. One must find an equilibrium between the two factors, which are opposite. If the pressure of oxygen is not raised too high, the arrangement of mixing is excellent, and the result will be perfect. From practice it is well known that, as the welding proceeds, the blowpipe becomes heated, and the gases, especially acetylene, expand. This causes a decrease in acetylene gas, and makes the flame at once oxidising.

From tests which have been made upon the consumption of the gases by the Congress on Autogenous Welding, getting fifty blowpipes from the different manufacturers (the average delivery of acetylene was fixed at 350 litres per hour, and the work to be executed lasted from thirty to forty minutes: the welders were experts), the best proportion of oxygen to acetylene was 1·12, the average 1·3, and the worst 1·9. A test was also made with the same blowpipe handled by two welders, one using oxygen at 28 pounds pressure and the other at 13 pounds. The proportion in the first case was 1·83, in the second 1·25, showing clearly the influence of excess pressure of oxygen on the consumption of the gas. These tests prove that, according to the type of blowpipe and the conditions of use, the consumption of oxygen for a constant delivery of acetylene can vary greatly and may double in volume. Not only is the oxygen consumed in excess of the theoretical amount a pure loss; its presence in the flame oxidises the metal, lowers the strength of the weld, and renders it brittle and porous. These considerations are important from the point of view of economy and good work, and those interested should carefully study them.

In the choosing of blowpipes many things are to be taken into

account; if it is to be used for continuous work on one thickness of metal, then the proper sized blowpipe should be chosen with a fixed delivery. Then, again, one must satisfy oneself that one is buying the best article, not so much as regards appearance or shape, as with a view to lowest consumption for the particular size of work; and a guarantee should be got from the makers for a stipulated hourly consumption. If the class of welding is changeable from thick to lighter materials, then a combined independent set with all interchangeable heads would be most suitable. This applies to small equipments in small shops. On the other hand, in large shops where a good number of operators are employed it is more economical to have fixed ones; they are not so delicate as the interchangeable, which, by the constant changing, suffer more wear.

The actual weight is often important in practical use. Sometimes welders say that the best blowpipes are those that are light in the hand; but unless they have attended instructional classes they have not the slightest knowledge of the consumption, or other details which must be settled before purchase. If the work is continuous, then a light blowpipe should be adopted, providing, of course, that the working is right, with the correct mixtures of gases and the consumption up to standard. If the work is heavy, such as some repairs which have to be done quickly, then a heavy type would be preferable.

The questions of working, the consumption of the gases, and the maintenance in the workshop, have been badly neglected in the past. As competition is getting keener daily, however, manufacturers are now interesting themselves in the details. One comes across many blowpipes which are well constructed and regulated, but have that tiresome striking back of the flame into the interior when the nozzle gets heated. This is a serious defect, because the welder generally increases the pressure of oxygen.

A guarantee should be got from the suppliers that this back-firing will not take place. The matter of consumption is a vital point as regards economy and cost. In large shops, where there are one hundred or more blowpipes in use at once, the saving in oxygen, with the very best designed blowpipes, giving a consumption of 1·3 of oxygen to 1 of acetylene, may amount to hundreds of pounds per year.

The author has made tests in this direction, one of which may be described here. Six blowpipes were used, two each of different manufacture, which we call A and A1, B and B1, C and C1. These tests were made on a $\frac{1}{8}$-inch plate, butt-welded, with 12-gauge thick

charcoal iron wire as the welding-rod. These tests lasted twenty-five minutes, and the following were the results:

A	and	A1	gave	1·3	of oxygen	to	1	of acetylene.
B	,,	B1	,,	1·4	,,		,,	,,
C	,,	C1	,,	1·75	,,		,,	,,

These are clear instances of the varying makes of blowpipes, and it at once demonstrates how important it is to have the very best designed blowpipes that are made. As a further illustration: suppose a bad blowpipe, using 1·75 of oxygen to 1 volume of acetylene; say that the consumption of the works is 4,000 cubic feet per month—that is, ten cylinders of 100 cubic feet each per week (many firms use this quantity per hour). Under these conditions it would be—

$$\frac{4000 \times 1{\cdot}3}{1{\cdot}75} = 2{,}971 \text{ cubic feet.}$$

The loss on a badly designed blowpipe is, therefore, 1,029 cubic feet, which, at 1d. per foot, is £4 5s. 9d. per month, and £51 9s. per year. This is only 10 cylinders per week—for larger users, the saving is greater. Apart from the loss, this excess of oxygen is highly detrimental to the welds, which is much more serious even than the loss of the gas.

Maintenance of Blowpipes.

Users of blowpipes must bear in mind always that they are articles of precision. They are made on delicate lines, to be delicately used, and not to hammer the weld as the author has seen some operators do. If carefully protected, they will last for years, just the same as when new. The taking to pieces must not be done with cumbersome tools, and in cleaning the nozzles, copper wire should be used. If the orifice is in any way enlarged, the slightest alteration in section produces derangement. The blowpipe section of the nozzle corresponds to a determined flow of oxygen, but the orifice for the flowing of the oxygen (the injector) remains unchanged, and any increase of the nozzle opening brings about a decrease of the velocity at the exit, which provokes a return of the flame into the interior of the blowpipe. When welding, the oxides, or particles of metal, produce the following results:

The delivery of the oxygen being variable and escaping under greater pressure than the acetylene, causes the flame to become oxidising in effect. The orifice being smaller for the passages of the

two gases, it is the stronger (the oxygen) that gets through in preference to the acetylene.

One must never allow oil or grease on the blowpipes or tubes, as in oxygen the oil may catch fire, and usually burns the rubber tube. This often happens to new blowpipes, in which the oil has got inside during manufacture. Do not take a blowpipe to pieces unless you are versed in its component parts, especially the inner

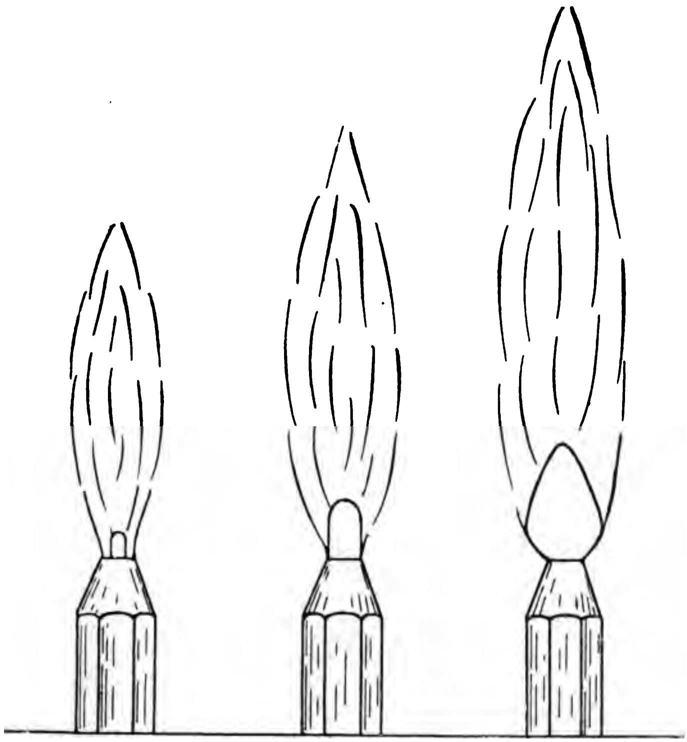


FIG. 26.—SHOWING THE CORRECT NEUTRAL FLAME, MIDDLE ONE CORRECT.

jet. This can rarely be adjusted again in the same place. Before sending out they are adjusted to a gauge, and one-thousandth of an inch out in this injector sets it all wrong. The best and quickest method is to return it to the makers for repairs.

If a blowpipe is obstructed by dust or other particles (generally lime dust carried over from the generator), these should be got away by fixing the rubber tube on the nozzle end of the blowpipe, leaving

the taps open and turning on the oxygen temporarily. This should blow it quite clean.

All operators should take great pride in blowpipes trusted to their care, and should, as I have said before, treat them as instruments of precision, keeping them ranged in good order and always polished.

The following are a few hints which will be found useful:

(1) See that the blowpipe is in good order, and no passages obstructed; also that the rubber tubes are correct and securely fixed, and the regulator on the oxygen cylinder in proper working order.

(2) See that you have ample acetylene and oxygen for the work in hand before commencing; it is injurious to the weld to stop in the middle.

(3) Turn the oxygen and acetylene taps full on, and light the blowpipe. The flame will then probably have an excess of acetylene, which should be reduced by gradually turning the acetylene tap on the blowpipe (or the outlet of the hydraulic valve, if there is no tap on the blowpipe), until the flame of the blowpipe has a clearly defined cone at the orifice. Fig. 26 shows what is required. The first one has an excess of acetylene; the second is correct; and the third has too much oxygen.

Blowpipes required for welding by the oxy-acetylene system must be chosen with care, must come up to the standard rules, and must not use more than 1·3 volumes of oxygen to 1 of acetylene. Also they must be easy of regulation, easy to handle, and able to keep up a regular and stable flame over long periods of working.

The following is an approximate table, giving the consumption of each size of blowpipe, for oxygen and acetylene; the size of the blowpipe to use, with the thickness of the plate being welded, and the length of feet that should be welded per hour. These tables are very useful and should have close attention.

Size of blowpipe		2	3	4	5	6	7	8	0	12	15
Approximate thickness of plate-joint					1/8	—	1/4"	3/8"	1/2	3/4	1"
Approximate consumption of gases per hour in cubic feet	oxygen	·7	3	6·5	9	16	23	34	48	75	100
	acetylene	·2	2	4·3	6·3	11	16	24	34	48	70
Feet welded per hour		40	30	20	15	12	9	7	4¼	2¾	1¼

CHAPTER XII

FLEXIBLE TUBING

No welding installation is complete without the means to conduct the gas from the oxygen cylinders and the hydraulic valves. The gas is conveyed by rubber tubing fixed on the proper connectors, attached to, firstly, the blowpipe; secondly, the hydraulic safety valve; and thirdly, the regulator on the oxygen cylinder. This rubber tubing is very important in any installation, and unless great care is taken by the welders, and the best quality of rubber purchased, it is an expensive maintenance charge. A cheap quality of rubber tubing is useless. Some of that on the market contains much more loading material than rubber. Such is dear at any price, although in appearance there is not much to choose. The best tubing consists of a good, soft, pliable inside rubber liner, of good stout thickness and not less than ⅜ inch inside clear diameter, reinforced by at least three-ply heavy woven canvas. It must suit the connectors on the blowpipes, regulators, and hydraulic safety valves. The fit should be just sufficient to secure a gas-tight joint at the connectors, but not too tight, so that it can be removed without undue strain or stretching of the tubing. There are 60 lineal feet in each coil of rubber tubing, and these usually cut into four pieces, making the requirements for two operators for two 15 feet each, one for the acetylene and one for the oxygen.

This rubber tubing is badly abused in the workshop. It is often blown open by the welders suddenly turning the oxygen on full at high pressure when the blowpipe tap is closed. Also at times they burn the tubing whilst welding, unknown to themselves. It may get accidentally thrown across the hot article which is being welded, and usually this is not found out till a hole has been burnt in it. Again, the tubing frequently gets cut by articles dropped on to it. On making an examination on the tubing being used, it will often be found that one sample in five is leaking, and the oxygen blowing away in the atmosphere. This is a costly item and should be watched very closely. Often, too, the tubing ignites at the connector of the blowpipe, because the rubber liner is curled up inside

and does not make a gas-tight joint; consequently, the oxygen escapes. The welder, not aware of this, continues welding till a spark flashes from the weld and ignites the rubber tubing at the connector of the blowpipe. It becomes incandescent immediately, probably burning the operator's hand, unless he is quick enough to drop the lighted blowpipe. It is necessary to have tubing of the correct size to fit the connectors, so as to avoid the bad practice of tying with wire.

Neither the connector nor the rubber should have any grease or oil on it. This will set up instant combustion if any oxygen catches it. If the end of the tubing is hard to get on, it should be dipped in water. This will ease the fixing on of the connectors. All connections, unfortunately, are not alike, which makes the fitting of tubing awkward where the connectors vary. It would be a great boon if all manufacturers of these connections were to standardise the sizes. It would cheapen production, and save much time lost in trying to get one size tubing on another size connector. For cutting blowpipes, the rubber tubing must be very much stronger, at least five-ply, owing to the greater pressure required for cutting iron and steel.

In many cases, when cutting very thick plate at high pressures, armoured tubing must be used.

The connectors on the blowpipes, regulators, hydraulic safety valves, should all be painted with shellac: this assists in keeping the tubing on without using wire, and makes a tight joint.

The present system of connectors for the rubber tubing is not very satisfactory, and new ones ought to be brought into service. These new ones consist of a union joint with coupling, so that one half of the union can be fitted on the gauge on the cylinder, and the other half fitted on the rubber tubing at the gauge end. These union couplings should also be attached to the hydraulic safety valve, and at the other end of the tubing to that which is attached to the gauge on the cylinder, and the same union couplings on the blowpipe.

The great advantage is that half the coupling is fixed permanently on each end of the tubing, thereby saving much time and preserving tubing.

CHAPTER XIII

SAFETY VALVES

It is a well-known fact that oxygen and acetylene are very highly explosive, and it is indispensable that all precautions should be taken to prevent the formation of these combustible gases. Their use is becoming more and more general in every part of the country, and we have therefore to put forward continually that precautions must be taken to prevent their formation, especially as their inflammation is very easily produced. With acetylene in use at a lower pressure than oxygen, the oxygen can return in the acetylene tubes and piping and so combine this gas in the generator. This occurs when there is a partial obstruction of the blowpipe, caused often by the welder allowing the blowpipe suddenly to touch the molten metal. The oxygen, being under pressure, and as the outlet is blocked, flows up the acetylene tube into the safety valve or hydraulic seal.

Therefore it is absolutely essential to place in the acetylene piping, between the generator and the rubber acetylene tubes on the blowpipes, an arrangement capable of arresting immediately any return of the oxygen. The object of a safety valve is to direct into the open air any oxygen which returns in the direction of the acetylene. It is not really meant to stop back-fire, but to prevent formation of a mixture of high explosive gases by the return of the flame.

The efficacy of such an apparatus must be absolute. So far a simply designed water seal has proved the most effective. It is one that cannot go wrong if the water level is kept right. In the hydraulic safety valve, two tubes emerge from a layer of water, one for the entry of the gas and the other open to the exterior, placed at different levels, constituting an absolute barrier against all return of the oxygen in the acetylene piping. Other arrangements, not based on this principle, should be rejected.

The illustration (Fig. 27) shows a good standard type made by the British Oxygen Company. The acetylene pipe from the gasholder or main supply is connected with tap *A*, and the acetylene tube leading to the blowpipe is connected with tap *B*. *C* is a loosely fitting lid, covering the cup in which the water is poured to charge

the seal pot *D* up to the level of the tap *E*. Taps *A* and *B* must be closed whilst the seal pot *D* is being charged with water. When water shows at tap *E*, immediately stop filling, and, allowing time for the surplus water to drain off, close the tap *E*. The lid *C* must

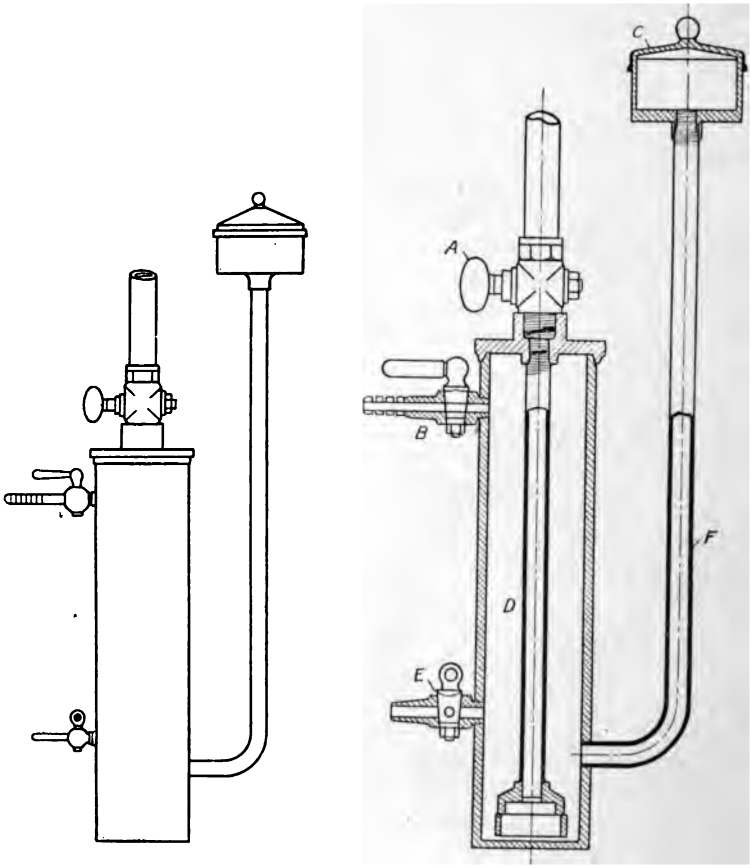


FIG. 27.—SAFETY VALVE, ELEVATION AND SECTIONAL.

then be replaced, and the taps *A* and *B* may be opened. The valve is then in working order.

The filling pipe F is made long enough to hold a column of water greater than the pressure of the acetylene generator. There should not be less than 8 inches of water. When at work the taps *A* and *B* must be open, and the supply of acetylene regulated by the tap on the blowpipe. Should the blowpipe nozzle at any time become

choked whilst the oxygen supply remains unchecked, the gas would be forced by its superior pressure along the acetylene tube. The back pressure thus caused, acting on the surface of the water in the seal pot *D*, would seal the acetylene pipe and force the water up the pipe *F*, displacing the liquid *C*. The hydraulic seal to the atmo-

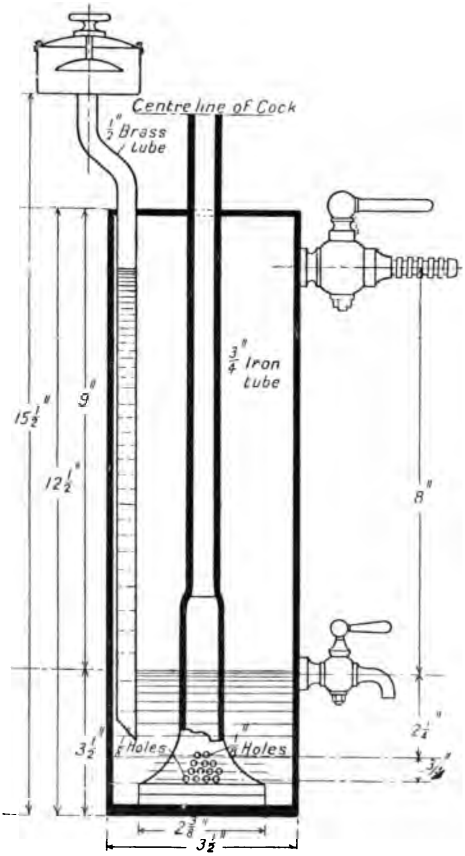


FIG. 28.—STANDARD SECTIONAL TYPE SAFETY VALVE.

sphere would thus be destroyed and both gases would escape until taps *A* and *B* were closed. Thus oxygen can never penetrate the acetylene supply beyond the hydraulic valve, provided the valve is kept properly filled.

There is really very little scope for modification in the design of these hydraulic valves. Two conditions, however, are essential

—viz., that the pipe conveying acetylene from the generator discharges into the water seal pot at a lower level than the opening to the vent; and that the vent pipe has a direct vertical discharge from the seal pot into the atmosphere.

All hydraulic back-pressure valves must be fixed on the acetylene supply pipe in a vertical position, as near to the blowpipe as convenience will permit. A good position is on a wall, with the bottom of the valve about 4 feet from the ground. The acetylene inlet pipe, coupled to the tap *A*, should extend vertically several feet above the tap. In cases where two or more blowpipes are worked from the same acetylene supply a separate hydraulic back-pressure valve should be employed for each.

One must be very careful in the choice of hydraulic back-pressure valves. A serious explosion, resulting in grave injuries to more than one workman and the total destruction of an acetylene generator, occurred in a munition works in Yorkshire in May, 1917. The holder formed part of a large plant which had been in successful operation for several years. Suspicion not unnaturally attached itself to the hydraulic valve.

No part of an oxy-acetylene outfit is more important or requires more careful attention than the hydraulic back-pressure valve. The explosion in question was caused by a badly designed hydraulic back-pressure valve of German make, in which there was a U-tube fitted, one end of which was fixed in the seal pot, and the difference between the U-pipe and the supply pipe was not sufficient to make a satisfactory seal. It is obvious that such a valve as this is useless as the means of preventing oxygen, at its superior pressure, from flowing back to the acetylene generator. The essential method of working is for the acetylene to bubble through a small height of water, which is nevertheless sufficient for covering the tube leading to the exterior, this being between the surface of the water and the level of the escaping acetylene. The valves must not be too large a gas capacity. The diameter of the body should just be sufficient to retain the level of the water constant, and the height enough to avoid drops of water reaching the outlet of the acetylene. The pipe which comes from the main supply into the seal pot should be of suitable diameter for maximum delivery to the largest blowpipe, so as to avoid all loss of pressure.

Often a pipe of small diameter, when a large blowpipe is used, causes eddies in the flow of the gas, through the delivery not being sufficient. The pipe which leads from the generator should go through the seal pot to within $\frac{1}{4}$ inch of the bottom. The bottom

end of this should be shaped in the form of a cone, and the cone should have small holes drilled in it to allow the gas to spread more when passing through the water. The height of the water in the seal pot should be about 3 inches clear of the top holes in the cone. This will be the position of the test tap. The acetylene outlet tap will be about 8 inches above this. The atmosphere pipe should be placed half-way between the test tap and the holes of the inlet acetylene pipe. The height of this pipe depends on the pressure of the acetylene, since the water rises in this tube as the pressure of the gas is increased. The height should be related to the level of the water in the valve, and should be more than the greatest possible pressure that would be used in the generators.

The illustration (Fig. 28) shows a valve that is infallible in working and is simple in construction. It can easily be made by any intelligent man. It consists of one piece of solid drawn tube, 3 inches inside diameter, with discs welded top and bottom. The bottom disc should have a quarter gas socket welded on, to take a tap to drain the water out when this is required for cleaning purposes. Gas sockets may also be welded at each of the tap holes for screwing them in. The acetylene inlet tube and the filling tube may both be welded in the disc top before welding the top on; but one must be careful to get the tubes fixed at the proper depth before welding them in.

The outside tube terminates in a funnel, which is used for filling the valve with water. This is covered by a lid. Well-designed and well-constructed hydraulic valves work well, are safe, and do not get out of order. It is only necessary to verify the level of the water daily, or every time it is left standing, and all operators should see, and make a practice of, trying the test tap not less than twice a day.

CHAPTER XIV

PURIFIERS

PURIFIERS generally consist of cylindrical vessels, usually made of sheet steel with an airtight lid or cover. They usually contain a series of trays holding the purifying materials. The calcium carbide, as now manufactured, is by no means a chemically pure substance. It includes a large number of foreign bodies. In crude acetylene, these are partly gaseous, partly liquid, partly solid. They may render the gas dangerous from the point of view of possible explosions. They, or the products derived from them on combustion, may be harmful to the health if inhaled. They are objectionable at the burner orifices, by determining, or assisting in, the defects of the metals of the weld.

A proper system of purification is one that is competent to remove the carbide impurities from the acetylene, as far as that removal is desirable or necessary. The generator impurities, as stated above, are oxygen, nitrogen, and lime in the form of fine dust. This lime may be extracted when the gas is passing from the generating chambers along the outlet pipe and down again through the bent pipe which dips in the water of the tank. As the gas bubbles through the water, part of the lime dust is removed. What escapes extraction may be removed by passing the gas through cotton-wool or felt, which is usually placed over the purifying material, in the top of the purifier.

The least volatile liquid impurities will be removed partly in the condenser (if one is fixed), partly in the washer (the tank), and partly by mechanical dry-scrubbing action of the solid purifying material in the chemical purifier. Sufficient removal of these generator impurities need throw no appreciable extra labour upon the consumer of acetylene, for one can readily select a type of generator in which the production is reduced to a minimum, using a cotton-wool or coke filter for the gas. A water washer, which is very useful in the plant, if only employed as a non-return valve between the generator and the main piping and the indispensable chemical puri-

fiers, will take out of the acetylene all the remaining generator impurities which need to, and can, be extracted.

In designing a washer for the extraction of the ammonia and sulphuretted hydrogen, it is necessary to see that the gas is brought into most intimate contact with the liquid, while no more pressure than can be avoided is lost. One volume of water only absorbs about 3 volumes of sulphuretted hydrogen at atmospheric temperature, but takes up some 600 volumes of ammonia; and, as ammonia always accompanies the sulphuretted hydrogen, the latter may be said to be absorbed in the washer by a solution of ammonia, a liquid in which sulphuretted hydrogen is much more soluble. Since the water only dissolves about an equal volume of acetylene, the liquid in the washer will continue to extract ammonia and sulphuretted hydrogen long after it is saturated with the hydrocarbon. To avoid waste of acetylene by dissolution in the clean water of the washer, the plan is sometimes adopted of introducing water into the generator through the washer so that, practically, the carbide is always attacked by a liquid saturated with acetylene. For compactness and simplicity of parts, the water of the holder seal is often used as a washing liquid. But unless the liquid of the seal is constantly renewed it will become offensive, and will act corrosively on the metal of the tank and bell.

The reason why the carbide impurities must be removed from acetylene is this: There are three compounds of phosphorus, all termed phosphuretted hydrogen or phosphine—a gas PH_2, a liquid P_2H_4, and a solid P_4H_2. The liquid is spontaneously inflammable in the presence of air—that is to say, it catches fire of itself, without the assistance of a spark or flame, immediately it comes in contact with the atmospheric oxygen. Being very volatile, it is easily carried away as vapour by any permanent gas. In commercial carbide it has been found that the highest amount of phosphine in the acetylene is 2·3 per cent., and this gas is capable of self-inflammation. Bullier states that acetylene must contain 80 per cent. of phosphine to render it spontaneously inflammable.

Ammonia is objectionable in acetylene because it corrodes the brass fittings and pipes, and because it is partly converted into nitrous and nitric acids as it passes through the flame.

Sulphur is objectionable in acetylene because it is converted into sulphurous and sulphuric anhyhrides, and their respective acids, as it passes through the flame.

Phosphorus is objectionable because, in similar circumstances, it produces phosphoric anhydride and phosphoric acid. Each of

these acids is harmful to the human system, sulphuric and phosphoric anhydrides (SO_2 and P_4O_{10}) acting as a specific irritant to the lungs of persons predisposed to affections of the bronchial organs.

Phosphorus, however, has a further harmful action. Sulphuric anhydride is an invisible gas, but phosphorous anhydride is a solid body, and is produced as an extremely fine, light, white, voluminous dust, which causes a more or less opaque haze. Phosphoric anhydride is also partly deposited in the solid state at the burner orifice,

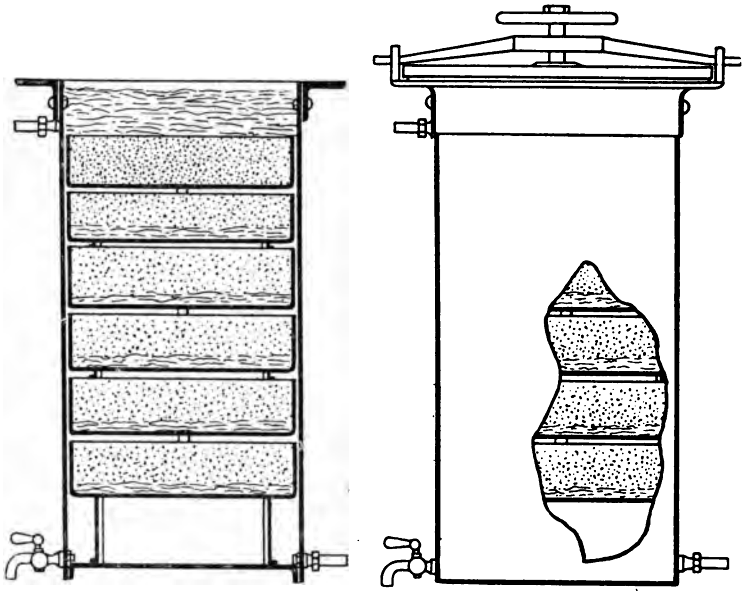


FIG. 29.—PURIFIER, SHOWING SECTION AND ELEVATION WITH PURIFYING MATERIAL.

and, always assisting in the deposition of carbon from any polymerised hydrocarbon in the acetylene, thus helps to block up and distort the orifices of the blowpipes.

Purifiers are usually made from sheet iron or steel and galvanised, and often in good plants contain a porcelain vessel for holding the purifying materials, as acid from some of these act on the mild steel shell, corroding it. Fig. 29 shows a purifier made from sheet steel, in which all the joints are welded, and the connecting pipes also welded in; the purifying material is put into trays, the bottom of which is perforated with small holes. The lowermost tray is set about 3 inches from the bottom, the other trays on the top of this,

leaving a space of about ½ inch between each tray. In the bottom of each tray is a layer of thin felt, to prevent the purifying material from passing through the holes and, secondly, to act as drier for the gas. On the top of all the trays is a layer of felt or cottón-wool, put in to extract the lime dust which has not been extracted by the water filter, and which came over with the gases. This dust is thereby prevented from getting into the blowpipe or the weld.

The purifying material should be lightly placed in the trays so as to allow the gases to go freely through the material without choking. It is usual for the inlet pipe to be at the bottom, and the

FIG. 30.—ATOX PURIFIER.

outlet pipe at the top, and a water tap must be placed at the bottom to allow the water from condensation to be run off from time to time. It is important that this be tried frequently, as the water may be sufficient to rise up, and through the purifying material, thereby nullifying its properties. The purifier may be placed anywhere between the generator and the main piping, but it is usually near the generator.

In the systematic purification of acetylene the practical question arises, How is the attendant to tell when the purifiers approach

exhaustion and need recharging? Heil has stated that the purity of the gas may be judged by its atmospheric flame given by a Bunsen burner. Pure acetylene gives a perfectly transparent, moderately dark blue flame, which has an inner cone of pale yellowish-green colour, whilst the impure gas yields a longer flame of an opaque orange-red tint with a bluish-red inner cone. It must be noted, however, that particles of lime dust in the gas may cause the atmospheric flame to be reddish or yellowish (through the action of calcium or sodium), quite apart from the ordinary impurities.

The simple method of ascertaining, definitely, whether a purifier is sufficiently active consists in the use of test papers prepared to the prescription of G. Keppler. These papers are cut to a convenient size, are put up in book form, and may be torn one at a time. In order to test whether the gas is sufficiently purified, one of the papers is moistened with hydrochloric acid of 10 per cent. strength, and the gas issuing from the blowpipe, or pet cock, is allowed to impinge on the moistened part. The original black or grey colour of paper is changed to white if the gas contains a notable amount of impurity, but remains unchanged if the gas is adequately purified.

The Keppler test papers turn white when the gas contains either ammonia phosphine, siliciuretted hydrogen, sulphuretted hydrogen, or organic sulphur compounds, but for carbon disulphide that change is slow. Thus the paper serves as a test for all impurities likely to occur in acetylene. The paper is a specially prepared black porous kind which has been dipped in a solution of mercuric chloride (corrosive sublimate) and dried. These papers can be obtained, put up in case with a bottle of acid for moistening them as required, from E. Merck, 16 Jewry Street, London, E.C. 3, or from the usual retail dealers in chemicals.

The sensitiveness of the test is quick. If a distinct white mark appears on the moistened paper when it is exposed for five minutes to a jet of acetylene, the latter is inadequately purified. If the gas has passed through a purifier this test indicates that the material is not efficient, that the purifier needs recharging.

The British Acetylene Association has issued the following set of regulations as to purifying materials and purifiers for acetylene:

(1) The purifying material shall remove phosphorus and sulphur compounds to a commercial degree—*e.g.*, not to a greater degree than will allow easy detection of escaping through its odour.

(2) The purifying material shall not yield any products capable of corroding the gas mains or fittings.

(3) The purifying material shall, if possible, be efficient as a

drying agent, but the Association does not consider this absolutely necessary.

(4) The purifying material shall not, under working conditions, be capable of forming explosive compounds or mixture. It is understood, naturally, that this condition does not apply to the unavoidable mixture of the acetylene and air formed when charging the purifier.

(5) The apparatus containing the purifying material shall be a simple construction and capable of being recharged by an inexperienced person without trouble. It should be so designed as to bring the gas into proper contact with the material.

(6) The containers and purifiers should be made of such materials as are dangerously affected by the respective materials used.

(7) No purifier should be sold without a card of instructions suitable for hanging up in some prominent place. Such instructions should be of the most detailed nature, and should not presuppose any expert knowledge whatever on the part of the operator.

CHAPTER XV

SELECTION AND INSTALLATION

It is not possible to give a direct answer to the question as to which is the best type of acetylene generator. There are no generators made by responsible firms which are not safe. Some are easier to charge and clean than others. Some require more frequent attention. Some have moving parts less likely to fail, or none at all to go wrong. There are contact apparatus on the market which appear to give little trouble. There is very little to choose, from the chemical and physical view, between the generators now on the market. A selection may rather be made on mechanical grounds.

The generator must be well able to produce gas as rapidly as ever it will be required during the longest time the blowpipe may be used. It must be strong and able to bear careless handling and frequent rough manipulation of its parts. It must be built of sound material, and galvanised after manufacture, so that it will not rust in a few years. Each and every part must be accessible, and its exterior visible. Its pipes for the gas must be large bore. The number of cocks, valves, and moving parts must be reduced to a minimum. It must be easy to clean, the waste lime must be readily removed. It must be so fitted with vent pipes that the pressure can never rise above that at which it is supposed to work. Apparatus that claims to be automatic should be perfectly automatic, the water or the carbide feed being locked automatically before the carbide store, the decomposing chamber, or the sludge cock can be opened.

The generating chamber must always be in communication with the atmosphere through a water seal vent pipe, the seal of which, if necessary, the gas can blow at any time. All apparatus should be fitted with rising holders, and the larger the better. The best place for a generator is in the open air, or a simple open shed, if well ventilated. The diameter of the mains and service-pipes for an acetylene installation must be such that the main or pipe will convey the maximum quantity of gas likely to be required to feed properly all the blowpipes which are connected to it, without an excessive actua-

ting pressure being called upon to drive the gas through the main or pipe.

The practical question in gas distribution is, What quantity of gas will a given actuating pressure cause to flow along a pipe of given length and given diameter? The solution of this question allows of the diameter of the pipes being arranged so far that they carry a required quantity of gas a given distance under the actuating pressure that is most convenient or appropriate. In order to avoid, as far as possible, expenditure and labour in repeating calculations, tables have been drawn up from Morel's formulæ, which will serve to give the requisite information as to the proper sizes of pipes to be used in the cases likely to be met with in ordinary practice.

Piping used for the distribution of acetylene must be sound in itself, and the joints perfectly tight. Ordinary gas barrel is not good enough. Joints for acetylene, like those for steam or high-pressure water, must be made tight by using well-threaded fittings, so as to secure metallic contact between pipe and socket. Acetylene service should, wherever possible, be laid with a fall, which may be very slight, towards a small closed vessel adjoining the gas-holder or purifier, in order that water deposited from the gas through condensation of aqueous vapour may run out of the pipe into that apparatus. Where it is impossible to secure an interrupted fall in that direction, there should be inserted in the service pipe at the lowest point of each dip it makes, a short length of pipe turned downwards and terminating in a plug or sound tap, to remove the condensed water.

When all the fittings have been connected, the whole system of pipes must be tested by putting it under a gas (or air) pressure of 9 to 12 inches of water, and observing on an attached pressure-gauge whether any fall in pressure occurs within fifteen minutes after the main inlet tap has been shut. The pressure required for this can be obtained by weighing the holder. If the gauge shows a fall of pressure of ¼ inch or more in these circumstances, the pipes must be examined until the leak is located, but it must never be searched for with a light. Fittings for acetylene must have perfectly sound joints and taps—common gas fittings will not do; the joints, taps, ball sockets, etc., are not ground accurately enough to prevent leakage. Fittings are now being specially made for acetylene, which is a step in the right direction.

The conditions which a generator should fulfil before it can be considered safe are as follows:

(1) The temperature in any part of the generator when run at the maximum rate for which it is designed, for a prolonged period,

should not exceed 130° C. This may be ascertained by placing short lengths of wire, drawn from fusible metal, in those parts of the apparatus in which heat is likely to be generated.

(2) The generator should have an efficiency of not less than 90 per cent., which, with carbide yielding 5 cubic feet per pound, would imply a yield of 4·5 cubic feet of gas for each pound of carbide used.

(3) The size of the pipes carrying the gas should be proportional to the maximum rate of generation, so that undue back-pressure from throttling may not occur.

(4) The carbide should be completely decomposed in the apparatus, so that the lime sludge discharged from the generator shall be incapable of generating more gas.

(5) The pressure at any part of the apparatus, on the side of the holder, should not exceed that of 250 inches of water, and on the service side of same, or where no gas-holder is provided, should not exceed 200 inches of water.

(6) The apparatus should give no tarry or other heavy condensation products from the decomposition of the carbide.

(7) In the use of a generator, regard should be had to the danger of a stoppage of the passage of the gas, and the resulting increase of pressure which may arise from the freezing of water. Where freezing may be anticipated, steps should be taken to prevent it.

(8) The apparatus should be so constructed that no lime sludge can gain access to any pipes intended for the passage or circulation of water.

(9) The air space in a generator before charging should be as small as possible.

(10) The use of copper should be avoided in such parts of the apparatus as are liable to come in contact with acetylene.

(11) Notice to be fixed on the generator house door—"No naked lights or smoking allowed."

(12) No repairs to, or alterations in, any part of a generator, purifier, or other vessel which has contained acetylene shall be commenced, nor, except for recharging, shall any such part or vessel be cleaned out, until it has been completely filled with water, so as to expel any acetylene or mixtures of air and acetylene which may remain in the vessel and may cause a risk of explosion.

Having described various forms of the items which go to form a well-designed acetylene installation, it may be useful to recapitulate briefly, with the object of showing the order in which they should be placed. From the generator the gas passes into a condenser to cool it and remove any tarry products. Next it enters a washing

apparatus filled with water to extract water-soluble impurities. If the generator is of the carbide-to-water pattern, the condenser may be omitted, and the washer is only required to retain any lime froth and to act as water seal or non-return valve. If the generator does not wash the gas, the washer must be large enough to act efficiently as such, and between it and the condenser should be put a mechanical filter to extract the dust. From the washer the acetylene travels to the holder. From the holder it passes through one or two purifiers, and then travels to the drier and the filter. If the holder does not throw a constant pressure, or if the purifier and the drier cause irregularities, a governor or regulator must be added to the drier. The acetylene is then ready to enter the service. When the gas generally leaves the generator house, a full-way stopcock must be put in the main.

Generator Residues.

According to the type of generator employed, the waste product removed therefrom varies from a moist powder to a thin cream or milk of lime. Any waste product which is quite liquid in its consistency must be completely decomposed and free from particles of calcium carbide of sensible magnitude. In the case of more solid residues, the less fluid they are the greater is the improbability (or the less is the evidence) that the carbide has been wholly spent with the apparatus. Imperfect decomposition of the carbide inside the generator not only means an obvious loss of economy, but its presence among the residues makes careful handling of those essential to avoid accidents, owing to a subsequent liberation of acetylene in some unsuitable and, perhaps, closed situation. A residue which is not conspicuously saturated with water must be taken out of the generator-house into the open air and flooded with water, being left in some uncovered receptacle for a sufficient time to ensure all the acetylene being drawn off. A residue which is liquid enough to flow should be run directly from the draw-off cock of the generator through a closed pipe to the outside, where, if it does not discharge into an open conduit, the waste pipe must be trapped, and a ventilating trap provided so that no gas can blow back into the generator-house.

As the acetylene is now brought through in the mains, it will be distributed to the operators through an hydraulic safety valve and rubber tubing to the blowpipes. It is usual to fix the main piping overhead, from which pipes are suspended, at specified distances, upon which pipes are attached an hydraulic safety valve.

It is necessary for each welder to have one hydraulic safety valve, or water seal, for each blowpipe. There should be welding tables or benches fixed running under the main piping. These tables or benches are generally constructed of iron or steel frames, with boiler-plate tops, and are made wide enough to allow welders to work opposite each other, therefore economising space. The arrangement of hydraulic safety valves is suspended from the main pipe, above the centre of the welding table, making it convenient and handy for the operators.

The next operation is to fill all the hydraulic safety valves with water until it runs out of the water-level test cock. When this has been done, the rubber tube may be fixed to the outlet tap of the hydraulic safety valve at the one end, and the blowpipe at the other end. Then another piece of tubing is taken and fixed on to the regulator (which is already fixed into the cylinder valve); the other end of the tubing to be fixed on to the oxygen tap of the blowpipe. All is now ready for the gases for welding. The acetylene should be turned on at the main cock or tap. After the generator has been charged with a proper quantity of calcium carbide, the holder filled with water, and the purifier charged, all should be ready for the acetylene to be let into the main piping. Pure acetylene will not come through to the blowpipe on the first starting up of the plant, owing to a quantity of air in the piping and bell, which has to be replaced by the acetylene as soon as generation takes place. Before starting generation, all the taps or cocks fixed in the main pipes should be left open to allow the air to escape as the acetylene starts to come through; as the acetylene has a very pungent smell, it can soon be observed when it begins to come through in quantities. As soon as this period arrives, the taps can all be shut off, and the blowpipe lit. The oxygen being on at the cylinder and regulator, and acetylene turned on at the hydraulic safety valve, and then the two taps on the blowpipe—the oxygen first and the acetylene after the blowpipe is lit—allow it to burn until a good white rigid cone appears. This will take some time, owing to the fact that at first starting up (as already explained) the main piping is partly full of air, although the taps on the main piping have been previously opened. This air mixes with the acetylene, ignites at the tip of the blowpipe, and gives a bluish flame almost like a Bunsen burner. The blowpipe is to remain lighted until the flame reaches a small violet-whitish jet of very clear outline, when it will indicate that the air is all out of the piping, and welding may be done.

CHAPTER XVI

METHODS OF WELDING

THE subject to which we are now about to proceed is one which should be very interesting to welding operators. My experience, throughout years of instruction of operators, is that they invariably want to handle a blowpipe before they have even the smallest information of welding or what it means. They soon find out, however, that it is best to start from the beginning.

With all appliances in order, and the blowpipe chosen, work can be proceeded with. The pieces to be welded consist of two pieces of angle iron, which are put on the top of the loose bricks on the welding table. The hydraulic safety valve is tested. The acetylene gas is turned on at the tap of the safety valve (the taps on the blowpipes being closed), then the taps on the regulator and the blowpipe are both opened and left open. The cylinder valve is open to let the oxygen through to the blowpipe. The oxygen should be turned off temporarily on the regulator until everything is ready and complete for welding, then the blowpipe may be lit, and the flame regulated. The blowpipe should be held in the hand, in the central position found by balancing. The weight of the rubber tubes will make the blowpipe feel balanced and light in the hand.

When commencing welding, the blowpipe should be pointing to the line of welding at a slight angle, so that the blowpipe will melt the metal in advance of the tip of the flame. One must not hold it at too large an angle, otherwise the molten metal will be blown on the cold surface. This point or tip of the flame—that is, the clear white cone—must not touch the metal, but must be about $\frac{1}{8}$ inch from it. This prevents oxidisation of the metal, and also prevents the nozzle of the blowpipe from being filled up with metal which is blown up with sparks. Further, a much neater weld is made with the flame above the molten mass than in it.

The blowpipe should be held freely in the hand, and the weld approached at one edge, care being taken that, as soon as the point of melting has been reached, the blowpipe shall be moved slowly forward to melt, say, $\frac{1}{4}$ inch from the edge. After the melting of this

second part, the blowpipe should be instantly passed over the edge to weld this, which process, from the previous heating, should be almost instantaneous. The object of heating the edge first and not welding, is to stop the molten metal from running from the edge. Nearly all operators, when learning, make this mistake. If, as directed, the second part is made molten and welded, and then the blowpipe is brought over to the end of the weld, this becomes molten, the blowpipe is moved to the third position, the film on the edge of the plate is not broken. Hence it supports the molten of the edge which has been done at the second heating. When proceeding with the welding the blowpipe must be moved forward very slowly, with a gyratory movement. The progress must be regular and continuous, so that the welding may be even and quickly done; and care must be taken that no welding shall be gone over twice, as each time it is done the metal loses some of its most important constituents and it is therefore burnt and weak. If it is necessary that the two edges of the article that is being welded shall be made molten together, the welding-rod used must also be in the same molten mass together. If the welding-rod is kept in close proximity to the cone of the flame, unity of fusion of both the edges of the weld and the welding-rod will take place, leaving an homogeneous weld.

It is best to train the hand, when engaged on small work, to make the flame of the blowpipe describe an elliptical movement, the longer diameter corresponding to double the width of the section of the article being welded. Also, at the same time that this is being performed, it is necessary to combine with this elliptical motion an advancing one; and, in the advancing, one must keep to the centre line of welding. In the welding of thick plates, where the article is either bevelled on one side or on both, the same elliptical and advancing movement as for light work is required; but a welding-rod is to be used constantly and regularly, so as to fill up the part that has been bevelled. In articles more than $\frac{5}{8}$ inch thick two layers have to be put on, one after the other, otherwise a sound weld could not be secured.

The welding-rod is held and directed by the left hand, and should be suspended between the top of the two fingers and the thumb, and over the side of the hand, almost as one holds a pen. It will be found that the rod will thus be balanced nicely for working with accuracy under the tip of the cone. The thickness of the welding-rod should be in proportion to the thickness of the article to be welded. It is very important, as previously stated, that the melting of the feeding-rod and the edges of the weld should take place at the same

time, so as to make the edges of the article and the feeding-rod combine and form one solid metal. Particular care must be taken to prevent the flowing metal from the rod falling on the unwelded edges of the article. This would cause the weld to be defective. It would be adhesion, not a weld. This, although so simple an error, is often committed, even by experienced welders. More care ought to be taken not to let these simple errors occur. No matter how well

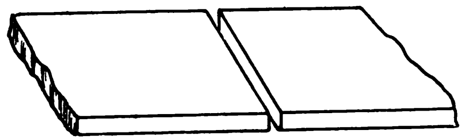


FIG. 31.—BUTT JOINT.

the other part of the weld is finished, if there is a defect like that of adhesion, it ruins the whole weld. In testing, the least sectional area will be taken. . Therefore, if the article is ½ inch thick, and adhesion is carried for ¼ inch deep, the weld is only half as strong. The smallest sectional area is ¼ inch thick, whereas the article is ½ inch thick, being a loss of strength of 50 per cent. Operators should

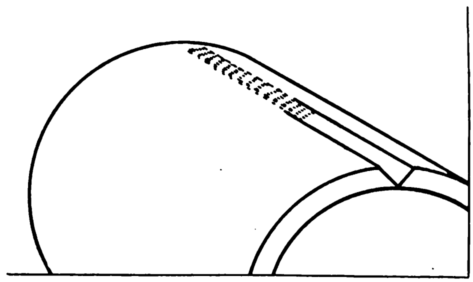


FIG. 32.—INDENTS, NOT SUFFICIENT WELDING-ROD ON.

make these small tests themselves, as this is the quickest and surest method of finding out their own defects.

The operator should make the rod melt at the same time as the welded edges. The rod is kept in the proximity of the flame, at almost melting-point, so that, as the two edges become melted, the rod is put or dropped on to the molten mass, by passing just through the cone; and, as the welding proceeds at a uniform speed, the rod is progressively worked at a sufficient rate of melting, to fill up the gap in the bevel and to complete the level of the weld to the same thickness as the article being welded. If operators will keep in

mind the information given so far, they should have some idea as to the melting of the article, to the mixing and the forming of the molten mass before solidification, and to the use of the blowpipe. They should be able to grasp the principle of the execution of welds; but more practice and more study are necessary to make proficient welders.

Homogeneous welding is the union of bodies by fusion. Usually the operator does not melt enough, does not get the edges molten before he lets the molten rod fall on the unwelded surface. Or he makes holes, and tries to fill them up by adding the feeding-rod, which usually drops on the cold surfaces. But by quiet determined tuition and practice the student soon comes to know what are the defects and makes great effort to remedy them. He must practise every form of welding, but must first of all master the commonest joints, such as the butt and the edge. These joints must be done over and over again before he is allowed to proceed with further kinds of welds. This is imperative if he intends to become a first-class operator. Two joints should be made: first, weld with welding-rod; second, without welding-rod; third, with welding-rod, hammer, and anneal.

The two tests should be butt and edge, and $\frac{1}{8}$-inch thick steel. "Bending test" may be made by fixing in the vice the article welded with the line of the weld just $\frac{1}{8}$ inch above the vice, then bend right over with a hammer. "Area test": Two pieces put at right angles, and weld along the corner, seam, then flatten out with hammer; see if the area is the same thickness as the material welded. Third test: Two pieces $\frac{1}{8}$ inch thick; butt and weld; use plenty of welding-rod. After welding, heat the piece up to white heat by blowpipe, hammer to thickness of metal; repeat the heating by the blowpipe, and allow to cool; and then bend in the vice. Watch the difference between the annealed one and the one not annealed. If these tests fracture when bent, repeat the welding and testing of these two articles until they can be done without cracking or fracture.

Operators in the first few courses of training generally point the flame on to one of the faces of the bevel. As the metal melts it runs down on the other "cold" side. It is usually covered over by the molten metal, and is not seen externally; but the defect is there, nevertheless. Operators must not allow this to occur, but must remember that the simultaneous and regular melting of the two edges of the weld and the welding-rod is a very important point. If good welds are to be obtained, this is a *sine qua non*. The beginning of the weld is always slower, and the end more rapid, because the

temperature of the article is increased as the line of welding reaches the end. The finishing must be done sharply, otherwise the metal gets so molten that the ends give way and allow the molten metal to run away.

We may now proceed to autogenous problems. The vast amount of welding carried through during the war was really amazing. The thousands engaged on this process were chiefly concerned with mild steel articles for military purposes. Millions of feet of sheet

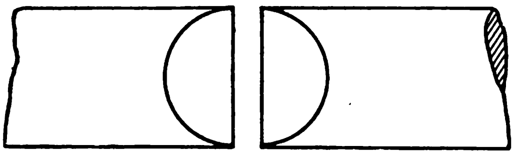


FIG. 33.—ROUND BAR BEVEL, CHISEL POINTS.

steel were welded, and the task of training these temporary operators was huge. Of course, there was no time to impart a thorough knowledge of welding. They were given just sufficient instruction to enable them to get along and practise for themselves. It was remarkable, however, how quickly they settled down to the plain welding of mild steel articles. These welds apparently are the most easy to obtain, but in reality, to do them as they ought to be done, so that they will

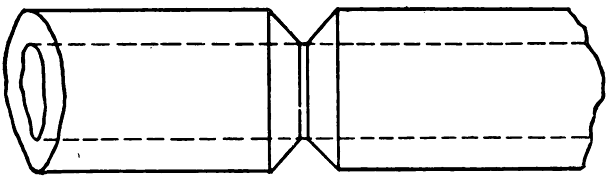


FIG. 34.—TUBE BEVEL.

stand any test applied, is not so easy. Indeed, they require on the part of the operator the utmost thought and care. It is well known that 90 per cent. of welding is in mild steel, therefore the operator will have to be taught the constituents and analysis of these metals. He must also make himself acquainted with the melting-points of the metals and their oxides. He must study the articles on the different metals in other parts of this book, and must especially learn to know the melting-points of all metals and their oxides. This is most important in the cases where the metals and their oxides differ in their melting-points. Take, for instance, steel

and aluminium. Steel is 1,600° C., aluminium 700° C. In the case of the oxides the difference is very much greater. Aluminium melts at 700° C., but its oxide melts at 1,600° C.; this is why operators do not find aluminium welding easy of execution. The metal itself readily forms in globules or beads, which do not run together owing to the outside film not being melted. These films are the oxide. The same happens to all metals, but others are not so much defined as aluminium.

There are many defects that happen in welding which could be avoided if operators would see if they were corrected as they went along. Some of the defects in welding mild steel will be described below.

The first is the lack of penetration—that is, either the power of the blowpipe has not been large enough or the operator has passed

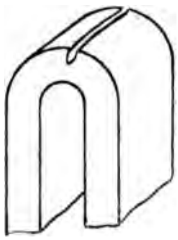


FIG. 35.—FRACTURE AFTER BENDING.

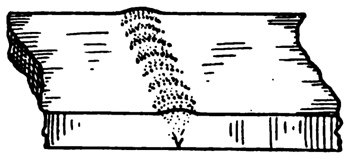


FIG. 36.—LACK OF PENETRATION.

over the line of welding far too fast. This lack of penetration is a serious defect, and is a defect that is commoner than any other, especially in the case of butt welding. By not penetrating right through the metal, the original thickness of the metal is reduced in sectional area, because the weld has only penetrated to two-thirds of its thickness. This is very serious, and in the case of tubing which has to stand pressure very often the weld gives before the full pressure is put on. This non-penetration occurs sometimes when the edges are not bevelled. The heat has not been sufficient for the fusion to go right through the whole thickness of the joint, and also the thickness not welded constitutes a starting-point for a break.

Figs. 35 and 36 show the weld, and the result of the bending.

On the other hand, operators should take care not to penetrate too far through, or the metal runs through from the molten bath above, and often leaves a conical hole which is difficult to fill up and, in doing so, generally oxidises the metal owing to being too long on the weld, and the metal is burnt.

Adhesion is another defect which operators often make, especially in thick bevelled work, owing either to not having a powerful enough blowpipe or to too heavy a pressure of oxygen, which "swills" the surface of the bevel, without taking time to make it liquid; dropping the liquid rod on this "swilled" surface causes it to stick or adhere. This is not fusion. Then, again, some operators do not melt both edges together, and therefore, again, no fusion or unity takes place. Again, many welds are interposed with oxide. This arises from several causes. The metal may not have been properly liquefied, which causes blowholes to form in the interior of the molten mass and remain after solidification. Likewise, if the metal gets too hot and boils, this causes gas to be imprisoned in the interior of the weld, also producing blow-holes. The defect may also arise from not attacking the bevelled edges of the weld suffi-

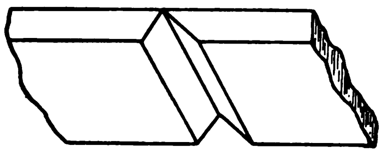


FIG. 37.—SINGLE BEVELLED JOINT.

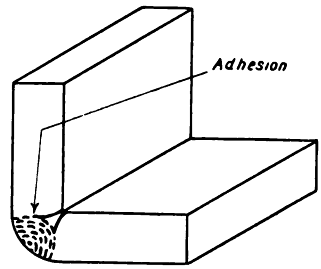


FIG. 38.—ADHESION, BAD WELD.

ciently, or attacking them unequally, or from the flowing of the metal or the liquid welding-rod on the edges that have not been melted.

Operators must pay attention to this point and understand that the molten metal flowing from the edge of the weld brings about adhesion if this part itself is not melted. It is very important indeed that, before the bevelled edges are melted, the bottom of the bevel should be melted first, so that as the sides of the bevel are melting, the liquid metal runs into the molten bath lying ready to receive it at the bottom of the bevel. If this is carried out there will be no adhesion.

It is important that all welds, no matter for what job, should always be well filled. There must be no part of the weld, on either side, under the full section of the metal which is being welded. If it is, the article loses its strength. This is almost as much to be avoided as a bad weld. Assume a tube is being welded $\frac{1}{4}$ inch thick. A butt joint is being made, and it is welded along the line of the

weld with what is, from the operator's point of view, a good weld. It is inspected and found to have, in two or three places along the outside lines, indents about $\frac{3}{32}$ inch deep. These indents were caused by the melting of the original metal, which flowed with the circular movement of the blowpipe, and left the indents behind. These should have been filled up with the welding-rod as the welding proceeded. Consequently, through this error, the tubing will not stand the full amount of test designed for $\frac{1}{4}$ inch thick. The finished sectional area is only $\frac{5}{32}$ inch thick. If $\frac{5}{32}$ would do, why use $\frac{1}{4}$ inch thick? Operators, however, must learn to keep the welds up to the thickness of articles. These articles are skilfully designed and the stresses all calculated out for the purposes to which they are to be put; therefore, if the welding all over is not up to that

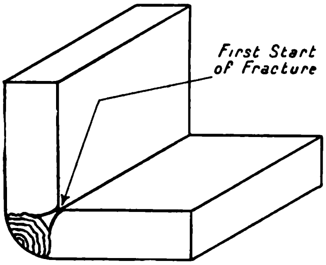


FIG. 39.—NOT FULLY PENETRATED, FIRST STARTING OF FRACTURE.

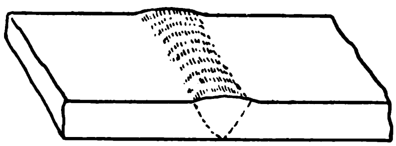


FIG. 40.—NOT PENETRATED THROUGH.

particular thickness the article is not so strong. In some cases this is important.

Tests for Welds.—The majority of defects are hidden in the body of the weld, and the operator is often ignorant of them. But there are many ways of testing welds, so that after he finds them out he should be able to overcome all his defects. This will take some time, but with patience and close study he should be successful. One cannot, of course, break joints of commercial work in order to get stresses and strains or examine the internal constitution. But with facilities to make his own test-pieces of similar metal to those he has worked with, the operator is able to make all the tests necessary, including resistance and elongation. Test by corrosion, or, as it is called, the micrographic test, may be applied to all metals of $\frac{3}{16}$ inch or over.

Two pieces of flat bar should be welded, about 3 inches long, butt-jointed, and then cut through the longitudinal way, across the weld. One of the faces is to be polished to a spotless surface, all

grease is removed, and the etching fluid, applied with a brush, soon exposes any defect, adhesion, or oxide. A plain black image appears which shows all flaws very plainly, and if it has been burnt this also can be clearly seen. It is important that the face be polished well and free from grease. The polishing does not disclose any defect, unless it be a bad one; but when the etching fluid is applied, the defects appear instantly. Therefore, if operators will from time to time practise these tests, they will soon remedy the defects.

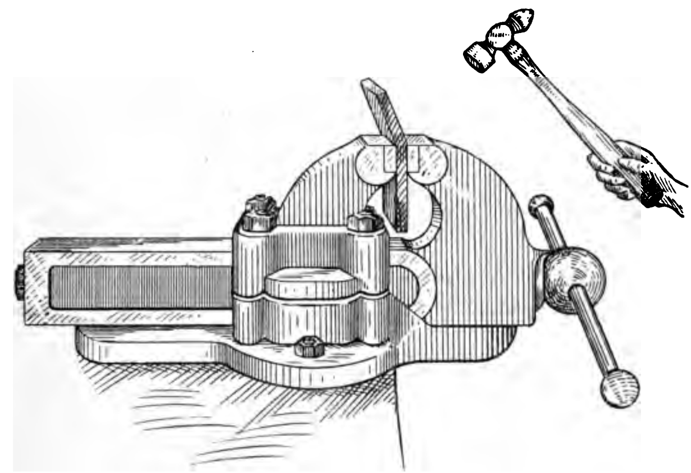


FIG. 41.—BENDING A TEST-PIECE IN A VICE.

Etching liquid may be as follows:

Iron and steel

Iodine solution	water	10 parts.
	potassium iodine	2 ,,
	iodine	1 part.

The solution is applied with a brush immediately the polished cut is ready. The structure develops almost suddenly, and in a few minutes the corrosion is sufficient. Wash with running water, dry with alcohol, and cover with a layer of varnish if the test is to be preserved. The test by bending is one applied in most technical schools, and is appropriate for all ductile metals. A test-piece may be made out of ¾-inch diameter round steel. This must be first prepared for welding by shaping two ends to chisel type ends. The reason why it must be pointed as a chisel is that, as the metal is welded, it falls down to the bottom where the chisel-point meets, at the centre of the round bar. If it were not for the chisel-point, the

article being round, the metal would run to the bottom of the welding table and spread about instead of building up. The welding of this round piece should be executed and finished off the same thickness as the bar itself, so as to give it a fair test when bending; after welding and cooling it can be put in the vice, with the weld just over the top of the jaws, the hammer applied in any direction. It should be bent over to a radius of 1½ inches. If this is done without a crack or fracture, the work will pass.

The hammering and annealing test is the best of all. Operators should weld several of these small test-pieces in various sections of steel. One-third of the test-pieces to be put through the three tests of corrosion—bending, hammering, and annealing—should be pieces where welding only has been done; one-third should be pieces which have been welded, annealed, and hammered; annealed and cooled slowly. A record of all these tests should be kept, and the result will be surprising. The illustration (Fig. 41) shows a test-piece in a vice; this is a very easy method of the bending test; students who can execute welds to stand this test should be able to tackle all ordinary commercial work.

CHAPTER XVII

PREPARATION OF WELDS

IT is impossible to overestimate the importance of thorough preparation of the work before the weld is actually attempted. Any time spent in this way is amply repaid afterwards in the easier execution thus made possible. The preparation varies considerably with the nature of the metal and the thickness and form and position of the parts or articles to be welded. It is impossible to lay down any hard-and-fast rules. For each metal we may have to adopt a different preparatory procedure. For instance, some of the metals have much lower melting-points than others, and must be dealt with accordingly.

The general principles obtaining in the best practice direct that the line of weld must be opened out—that is, the two sides bevelled, each to 45 degrees, making an angle of 90 degrees. This is to make certain that the weld shall be penetrated, and not merely sealed over. The welding must be done from the bottom of the bevel and properly filled in with the welding-rod, the metal at the edges being molten at the same time, so as to unite with the molten rod; the two combining make a good sound weld. Bevelling also increases the area of the surface of the weld, thereby strengthening the latter. It allows the addition of a larger quantity of metal of better quality, since rods of pure iron are added to the welds. Bevelling is carried out on thicknesses of $\frac{1}{4}$ inch. After it reaches $\frac{1}{2}$ inch and over in thickness, the bevel should be on both sides. The illustrations on p 94 show two pieces.

It is essential that the line of welding should be thoroughly cleaned (particularly in the case of aluminium), either by hand tools or by some chemical agent. Too much stress cannot be put on this, as welders often find. The most important part of the preparation is that of arranging the pieces to be welded in such a position that there will be no deformation, fractures, cracks, or internal strains, and that they will be linable at the conclusion of the operation. This applies chiefly to cast-iron articles, which are generally

intricate castings of various thicknesses and irregular shapes and are often cumbersome.

This is a point in which the skill of the operator is revealed, as there are no fixed rules to guide him. Welders too often fail to take sufficient precautions to keep the article adjusted and in a correct position for welding, so as to allow for that phenomenon known as expansion and contraction, and to leave the welded article linable at the finish. One must keep in mind that old maxim:

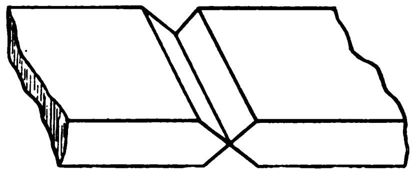


FIG. 42.—FLAT BAR DOUBLE BEVEL.

" What is worth doing is worth doing well." A weld well prepared is half done. As the result in welding depends to a certain degree on how the preparation has been carried out, one cannot spend too much on it, especially where intricate, uneven castings are concerned. It is the interested, careful, and thoughtful workman who gets success in the welding of such articles.

Bevelling should be done on both sides, as has been said, if over

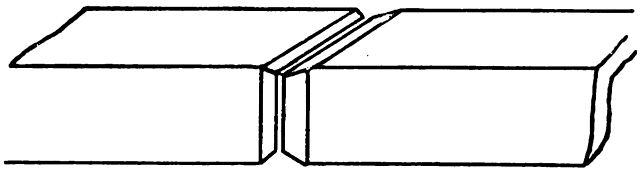


FIG. 43.—ANGLE IRON, BEVELLED ONE SIDE.

$\frac{1}{2}$ inch thick. If it cannot be got from both sides, then a deeper bevel must be made on the one side. Operators sometimes do not bother about bevelling, even if it is a case of $\frac{1}{2}$ inch thick without bevelling. To omit it always leads to bad results—such as bad penetration, adhesion, or overheating of the metal—and usually leaves about $\frac{1}{8}$ inch unwelded at the bottom edge. This reduces the sectional area, and is the means of starting a fracture (see the illustrations below), which is what happens when the articles are not welded through. If the above defective weld were tested, it would hardly stand a tensile test of three-fifths of the original

strength of the metal. Taking a good view of the above section, one sees that the weld does not touch the bottom joint of the bar. Further, it can be clearly observed that the molten metal did not penetrate through the full thickness, but formed itself into a semicircular mass at the bottom joint of the bar. This semicircular line reduces very much the area of the weld, and with it the strength. If a proper weld had been made, a $\frac{3}{8}$-inch plate would have been quite

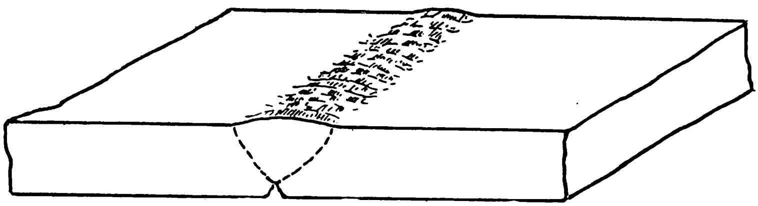


FIG. 44.—NOT PENETRATED.

as strong, and a great saving of material in the thickness of the respective plates would have been effected. In the illustrations the lines marked *A* and *B* show the thickness of the metal not welded. This is a great consideration from an engineer's point of view. He designs work calculated, on a specified thickness, to stand certain stresses; and it may, in any particular instance, be a very important

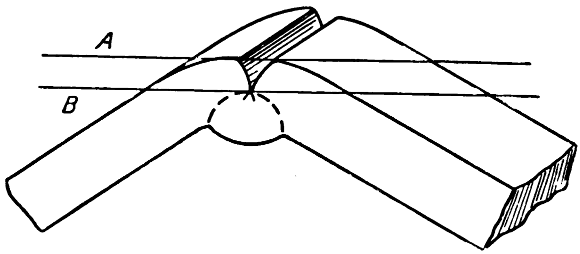


FIG. 45.—SPACE BETWEEN *A* AND *B* SHOWS AMOUNT UNWELDED, AND FRACTURE WHEN BENT.

job, where the stresses must be kept up to counteract the design. But if a bad weld is made and does not penetrate to the thickness, then the article will fail, and cause heavy loss. On the other hand, if one was sure of always penetrating the weld (which can only be done by preparing and bevelling), articles can be designed with lighter materials, thus saving expense.

The above sketches show very clearly how defects occur; the welding has not been penetrated through the whole thickness,

hence the strength is not up to the thickness of the original metal. Upon bending the bar, the unwelded line opened, and also started a fracture along the line of welding.

One cannot be too emphatic in stating that pure metals, pure welding-rods, pure gases, are most essential to good welds. Adjustment before welding is a point in which the experience and skill of the operator tells. There are very few rules for his guidance, as the articles are so different that each one has its own particular scheme. Upon any work but that of the simplest character, failure to grasp and apply the laws of expansion means partial or total ruin of the work. It is impossible to control expansion and contraction

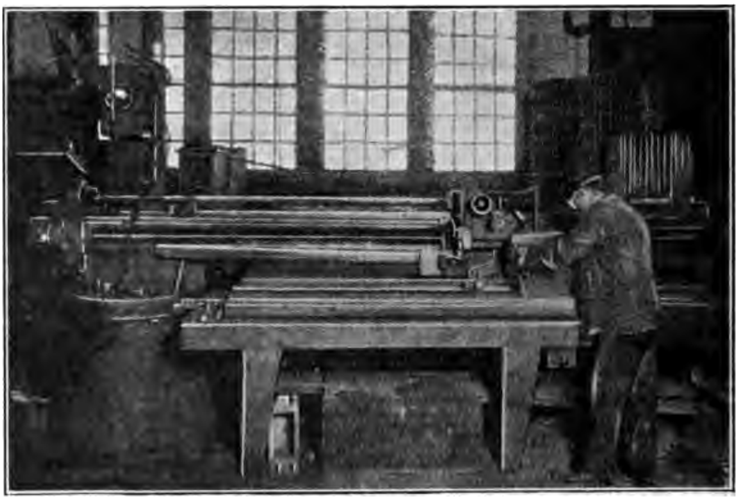


Fig. 46.—Machine Operator Welding Seams 116 Inches Long in Corrugated Sheets for Transformers.

by physical or mechanical forces. The only way to prevent disastrous results is to foresee the probable direction and extent of the phenomena and nullify the effect by preheating the whole or certain parts of the work, either by the blowpipe or the welder's furnace, the latter being recommended.

Operators must take precautions with all articles of non-ductile metals, to see that they are all properly adjusted, and carefully fixed at some part of them, to prevent them being moved or disturbed during the process of welding. They must provide that expansion and contraction shall take place uniformly, so that the

article is not, after welding, distorted in any way nor out of alinement. There are various ways of making these fixtures, and a series of different sizes should be kept. One is illustrated below, which is easily manipulated, even when hot from the furnace.

Expansion in physics is an enlargement or increase in the bulk of bodies, in consequence of a change of their temperature. This is one of the most general effects of heat, being common to all bodies whatsoever, whether solid or fluid. The expansion of solid bodies is determined by the pyrometer. One can realise the force of expansion from water that has frozen in an enclosed vessel or pipe. When the careless motorist leaves the cooling water of the engine in the water-jacket of the cylinder overnight, on a frosty day, the next

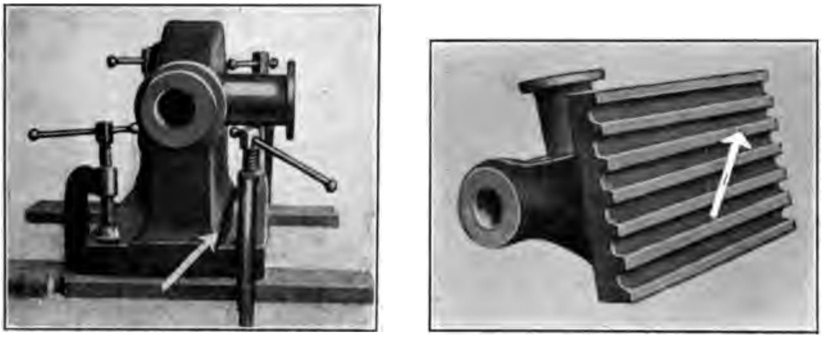


FIG. 47.—CASTING BROKEN.
Left: Bevelled and cramped setting for welding. Right: Welding completed.

morning there may be ice. On which heating by water or otherwise, the ice expanded, and this powerful force fractures the cylinder water-jacket owing to there being no outlet for the expansion.

This same phenomenon is seen with all cast-iron articles. It is useless to attempt by force to oppose this expansion and contraction. The method is to avoid or limit the consequences. If not, any welding done on non-ductile articles will surely cause deformation, cracks, and internal strains. The whole articles should be raised to a temperature, in the case of cast iron, of not less than 900° C., and not exceeding 1,100° C., and then quickly welded, and returned to the annealing furnace to cool slowly.

It must be understood that there is no other means of obtaining good results on non-ductile articles, except that of preheating and annealing on properly designed and well-thought-out lines. In cases

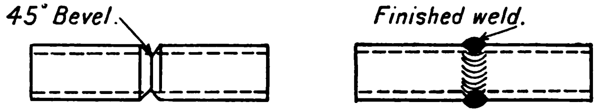


Fig. 48. Proper set up for butt welding of pipe, and finished weld.

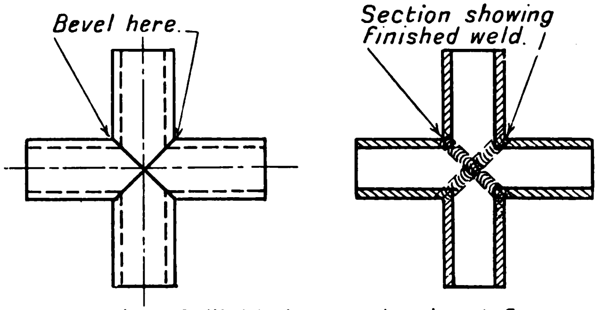


Fig. 49. Welded cross in pipe, left, bevel right, welded.

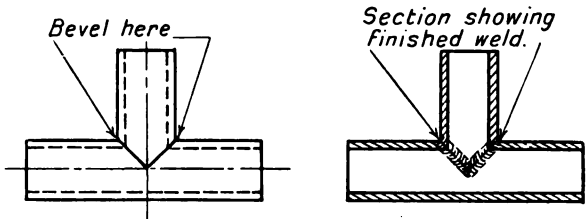


Fig. 50. Showing construction of T pipe, bevel and weld.

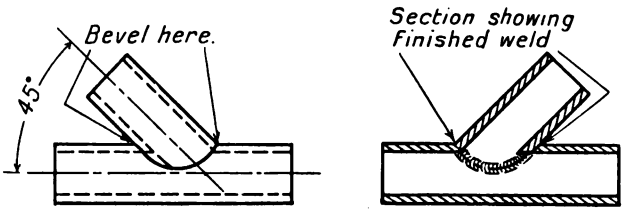


Fig. 51. Showing pipe at 45 degrees, weld and bevel.

FIGS. 48 TO 51.

where the articles are free to expand and contract and are fairly even in thickness and size, welding may be done without preheating. These articles will not crack when welding; but they are few, and should be carefully watched. After welding they should be placed in the annealing oven to remove all internal strains, and left to cool slowly.

The illustration on p. 97 is a case where it is not necessary to take expansion into consideration, as there are no tied ends. The casting may therefore be welded from the cold state; but, from an economical point of view, it should be heated to save the gas. The illustration referred to shows how a casting should be prepared for welding. The line of bevelling can be seen; the under side is similarly bevelled; the fixing of the cramps will be noted, holding the casting in position while the welding is performed.

In making the set-up for butt-welding pipes the edges should be separated sufficiently to allow the heat of the welding flame to drive all the way to the bottom of the weld. This separation, however, should not exceed $\frac{1}{8}$ inch, because too great separation is conducive to the formation of large bumps of metal within the pipes, which is very undesirable. Many operators butt the edges of the pipe "square up" and do not attempt to secure complete penetration. The weld is slightly reinforced and is virtually as strong as any portion of the pipe. The edges of the butt weld in the pipe and, more particularly, those of other fittings shown herewith should be bevelled Simple as these lay-outs appear, the average operator experiences more or less difficulty in getting the various parts to line up satisfactorily.

Figs. 48 to 51 show several tube joints, described above.

CHAPTER XVIII

WELDING TABLES

SMALL welding tables are used in both small and large workshops. There is quite a variety of types, from which one may select any particular one. They are built so as to give an easy position to the operator, who can work all round it.

This facilitates the task very much, and the weld is done quicker and better. The tables are portable and can be moved anywhere.

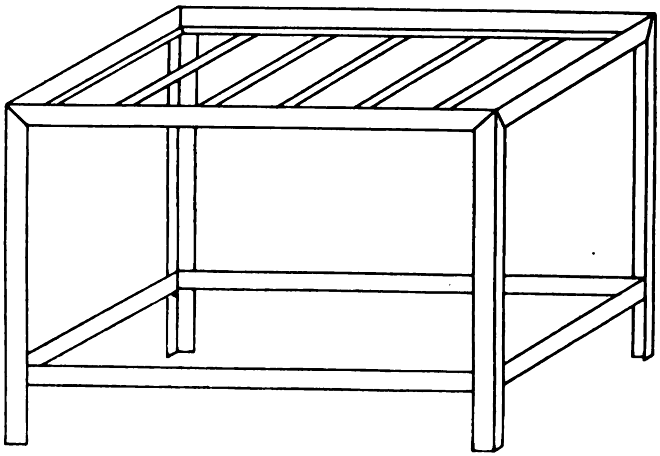


FIG. 52.—MILD STEEL OPERATOR'S TABLE.

They are usually constructed of angle-iron formation, and all the joints are welded. They may be light, and $1\frac{1}{4}$ by $\frac{1}{8}$ angle steel is strong enough for all ordinary purposes. The making is quite simple, being a matter of a few hours for any intelligent operator. Firstly, there are two frames, say, 2′ 9″ × 1′ 9″, which can be made in one piece; cut a **V** out of each corner; then bend at those places where cut out and weld up. Then the four legs should be welded to the frames, the one of which is on the top of, and the other inside, the legs, 8 inches from the bottom. This bottom frame should

be fitted with a mild steel plate, dropped closely into the angle frame, forming a tool table, where the operator can keep his tools and welding-rods. Tables are usually made 2 feet 3 inches high, but this may be altered to any height.

The following are illustrations of ordinary types, but they may be varied to suit circumstances.

One of them is shown plain and one with fire-bricks. Notice strips welded across the top frame to carry the bricks; the other is shown with fire-bricks in position. It is very necessary for fire-bricks to be put under articles to be welded, because the brick retains

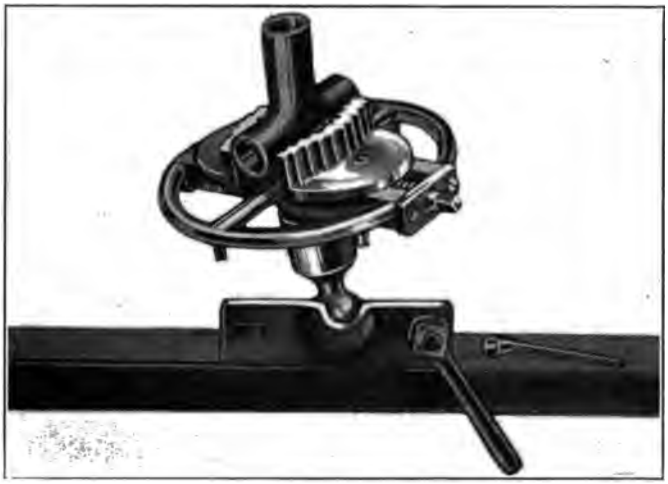


FIG. 53.—ADJUSTABLE WELDING TABLE, WITH VICE ATTACHED.

the heat, which assists the heating of the articles being welded, thereby saving gas. This is much better than having a bare steel-plate table, which often warps by the continual heating. The size of the top may be determined by the layer of bricks, and these should be laid out before the frame of the table is made, so as to get the correct size for the bricks to fit well together.

Fig. 53 is an adjustable type and can be turned at any angle. This is found exceptionally useful on repairs, when the welding is not horizontal. One has a vice attachment, and is very useful.

In large shops, where there are a large number of operators on repetition work, it is a practice to construct long tables at which thirty to forty operators can all work. They usually work face to

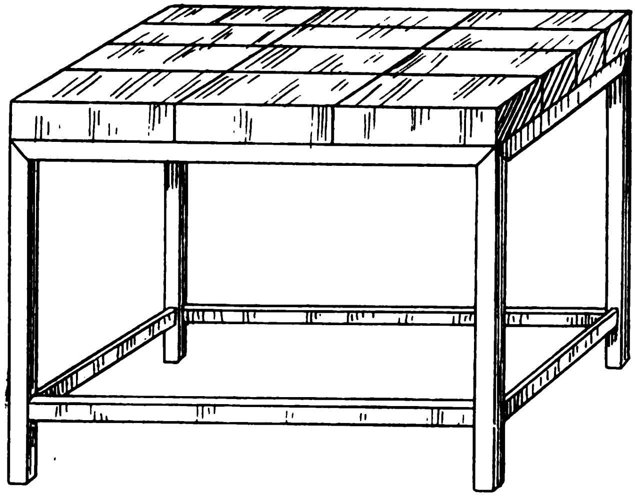


FIG. 54.—WELDING TABLE WITH FIRE-BRICKS.

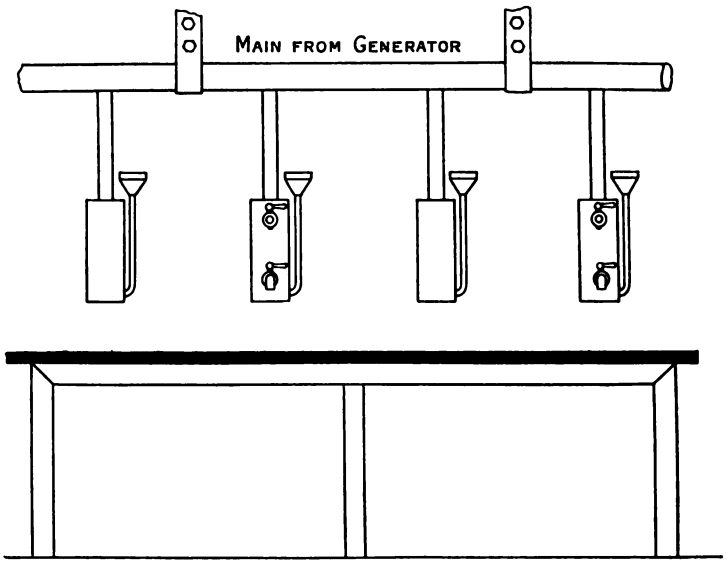


FIG. 55.—TABLE FOR A NUMBER OF OPERATORS.

face—that is, in pairs each side of the table. The acetylene main gas pipe is usually brought over the centre of the table, and the hydraulic safety valves are suspended from the main supply to a convenient position for the operators. They are spaced according to the requirements of the articles being welded without crowding.

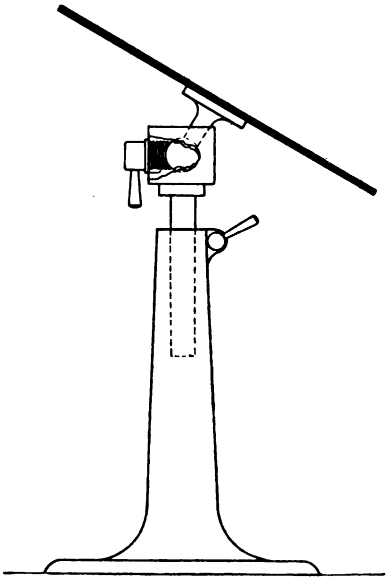


FIG. 56.—TILTING TABLE.
Articles can be bolted on.

In construction, these tables are almost identical with the smaller ones, with the exception that no frames are used, except the framing under the boiler-plate top. Such large tables usually have large flat bricks, about $1\frac{1}{2}$ inches thick. Fig. 55 is a sketch of one, showing the position of the acetylene main gas-supply, from which are suspended the hydraulic safety valves, one for each operator. The tables may be extended to any length, to the limit of the shop and the supply of acetylene.

CHAPTER XIX

FURNACES FOR HEATING

In the repair of non-ductiles, it is necessary to heat them up before the welding can take place. It is impossible to make satisfactory welds of cast-iron or aluminium articles without first preheating to a level temperature. If an attempt is made to weld any articles of the metals stated above, without getting hot all over, fractures take place. For instance, take a casting of iron just as it is, without preheating. Apply the blowpipe at any place, get a good heat, and the result is that you will hear it crack in some part other than where heated. When the casting gets cold again, further fractures are sure to occur. These are caused by the uneven heating of the

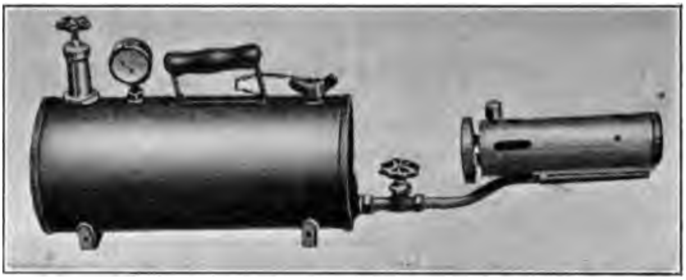


Fig. 57.—Kerosene Preheating Torch.

article in one place with the blowpipe, causing the non-conducting metal to expand where it was hot, while the cold part of the casting remained normal.

The methods adopted to overcome this expansion and contraction on non-ductile articles are very simple, if care is taken to provide the right appliances. One is to use a furnace with coal, coke, charcoal, or gas. Coal would be all right in a properly constructed furnace, where the flame is reverberatory, and a second floor has been made for the heating of the articles which are not in actual contact with the fire. But the author's experience is that this method is much too costly to maintain. The expense would be

prohibitive in a small shop, unless there was a good quantity of castings to weld daily. Also the heat is too fierce, and would not do at all for aluminium, which would probably collapse before it could be got out. The coal furnace should only be used in large shops. Although there are many of these furnaces being used, with coal, coke, and charcoal, and, to a certain degree, giving

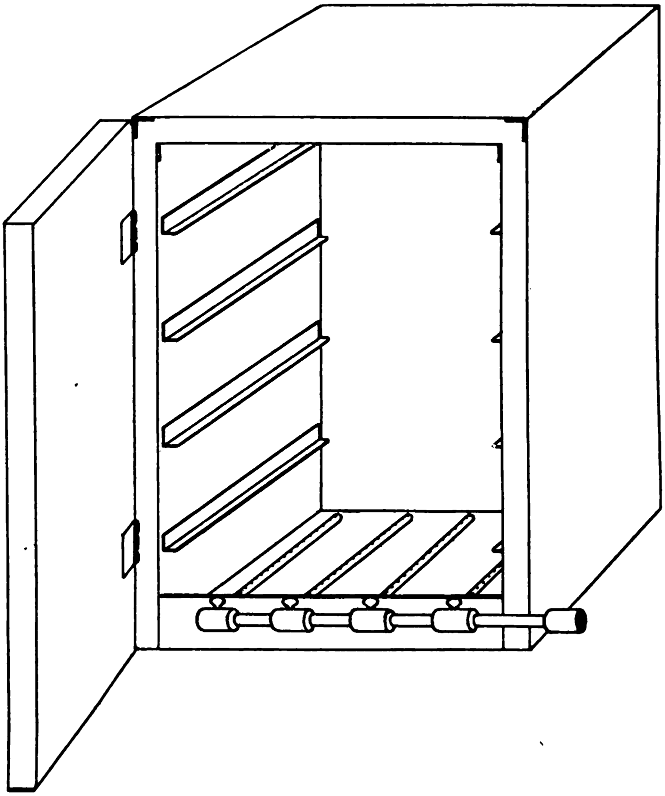


Fig. 58.—Gas-Heated Preheating Oven.

satisfaction, they are generally employed in conjunction with other work. The best method, with the least initial outlay, the most economical working, and the best even heating, is a furnace heated by gas at either ordinary or high pressure. Fig. 58 shows an excellent type, which gives exceptionally good results; it is not hard to make, and it will not be expensive.

Fig. 57 shows a preheating kerosene torch. This is ideal for

the repair shop; it is light, portable, and owing to a patented sliding valve, can be operated in any position. It produces a clean even flame of about 3,000° F. and 24 inches long. It consumes about 1 gallon of kerosene per hour. The tank capacity is 3 gallons. The burner thoroughly vaporises the kerosene, and the flame cannot blow out in the wind. It is very good for preheating work and also for annealing. The weight is 25 pounds.

The preheating oven or furnace shown on p. 105 is easy to construct from sheet steel. It was designed by the author, and has proved very efficient in use. It may be made any size to suit the work in hand. The one illustrated is 4 feet deep, 3½ feet wide, 3 feet long. The construction consists of an inner and outer casing, with

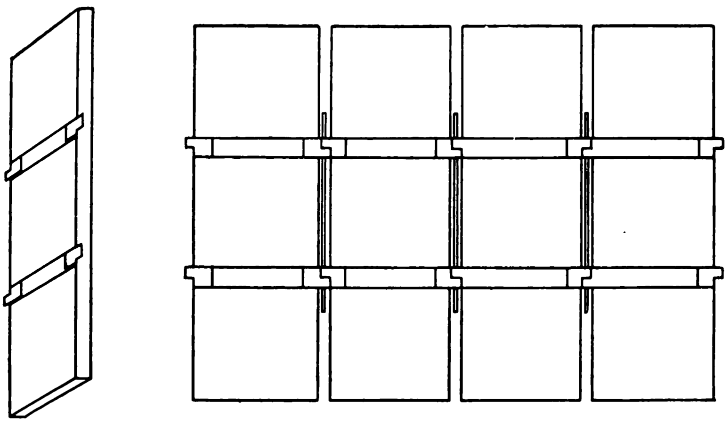


Fig. 59.—Folding Asbestos Screen, for Preheating Furnace.

1½ inches space between them, filled with asbestos. The back of the stove (inner and outer) must have the asbestos put between before bolting up the stove. There is an outlet at the back, near the top, to allow the burnt gases to escape, and the piping should be carried from the outlet to the atmosphere. On the inside of the stove are bearers or ledges for perforated trays, in which trays the articles for heating are fixed. The door is also made of two sheets of steel, with asbestos between them, and fits very closely to prevent any cold air from getting into the interior. Along the bottom are four Bunsen burners. These may be purchased from any reliable firm, but they must be the best that can be got.

A great saving in gas can be made by adopting, for the purpose of extracting all the heat from gas, a folding asbestos cover as in Fig. 59. It is made like a fourfold screen. After the article to be

heated is put in the stove, and before the gases are lit, it is placed on the top of the article. When the gases are lit, this cover concentrates the whole of the heat, thereby getting the article heated in a much shorter time, and saving quite 50 per cent. of the gas. This asbestos cover can be used for preheating and also for annealing. The screen described may be made in smaller or larger sizes to suit the work required. The perforated tray in the furnace is made to draw out with the article on it.

The handling of castings, such as a four-cylinder motor casting, when hot, is a very troublesome job if there are no proper appliances. Hence, fractures often occur through not getting the articles quickly enough into the annealing furnace, and allowing the temperature to fall into the expansion zone—that is, 850° C. The author has

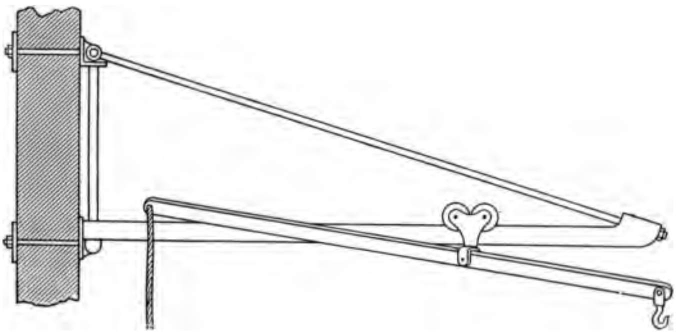


FIG. 60.—LIGHT LIFTING CRANE FOR USE IN LIFTING CASTINGS IN AND OUT OF THE PREHEATING FURNACE.

known this to occur on many occasions. Good welds have been executed, but they have been left one or two minutes too long before getting them into the annealing furnace, and very often the fracture is much larger than the original fracture. An appliance which will be found to overcome this difficulty of removing and inserting the hot articles rapidly, with ease and comfort, is shown in Fig. 60. This should be installed in all workshops where they are dealing with heavy repairs, which have to be preheated. It is simply a small swinging overhead crane, very lightly built, to carry about 5 cwt. It has two small wheels, running along a flat bar on edge. Suspended from the plates of the wheels is a lever about 9 feet long, a hook on the end, and a rope at the other.

The rope is for lifting the weight suspended at the other end; on the hook may be hung a two- or four-legged chain to lift the articles

already fixed on the oven tray. The hot casting may thus be put in and out of the oven or furnace with ease, and without any of the welders getting burnt.

The phenomenon of expansion and contraction with reference to metals is one of the most important problems in the welding processes. No operator can become competent without devoting long study to it. Cast iron is a non-ductile metal—that is, it can only expand and contract in its whole piece. Hence, if heat is applied to one part of the article, the heated part becomes expanded past its elastic limit. The cold part of the article does not expand and the heated part is therefore fractured. On the other hand, if the whole article had been heated, by putting in a proper heating furnace, and the heat carefully regulated until it had reached a minimum of 900° C., the article could have then been taken from the furnace and put on the welding table, welded, and put back into the annealing furnace and allowed to cool slowly, preventing any cold air from getting near it, when the article would be quite sound without crack or fracture.

This operation of expansion and contraction is so important, and the methods to counteract it are so easy, sure, and effective, that, in all cases where welding of non-ductile articles is done, one must see to it that these operations of preheating and annealing are carried out.

CHAPTER XX

IRON AND STEEL

THE mechanical properties of metals are often, in a great measure, dependent on the thermal treatment to which they have been subjected. There can be no question that the application of heat to a metal may produce a remarkable molecular change in its structure, the nature of the change depending on that of the metal, and on the treatment it has undergone. It will be well, therefore, to consider carefully what happens when the metals are submitted to three principal operations involving thermal treatment, which are known respectively as annealing, hardening, and tempering. Usually all three are intimately related. Annealing may be defined as the release of the strain in metals, which may itself have been produced by mechanical treatment, such as hammering, rolling, or wire-drawing, or by either rapid or slow cooling from a more or less elevated temperature.

As an example of the former, it may be mentioned that metals and alloys which have been rendered excessively hard by rolling are heated usually to bright redness and allowed to cool slowly. In the case of copper it does not appear to be important whether the cooling is slow or rapid, and in recent years much experimental evidence has been accumulated which tends to show that, in the case of certain metals which have been hardened, a more or less prolonged exposure to a low temperature under 100° C. will sensibly anneal them. On the other hand, the rapidity with which cooling is effected is very important. Bronze containing about 20 per cent. of tin is rendered very malleable by rapid cooling. In the case of iron and steel the thermal treatment is especially important.

Steel, it must be remembered, is modified iron. The name iron is, in fact, a comprehensive one, for the mechanical behaviour of the metal is so singularly changed by influences acting from within and without its mass as to lead many to think that iron and steel must be two distinct metals: their properties are so different. Pure iron may be prepared in a form as pliable and soft as copper —for instance, the charcoal used for welding. Steel can readily be made sufficiently hard to scratch glass. Notwithstanding this extra-

ordinary variation in the physical properties of iron and certain kinds of steel, the chemical difference between them is small, and would hardly secure attention if it were not for the importance of the results to which it gives rise.

It is necessary to consider the nature of the transformations which iron can sustain, and to see how it differs from steel. Its most useful and advantageous property is that of becoming extremely hard when ignited and plunged in cold water, the hardness produced being greater in proportion as the steel is hotter and the water colder. The colours which appear on the surface of steel slowly heated direct the artist in tempering or reducing the hardness of steel to any determinate standard.

Hardening is the result of rapidly cooling a strongly heated mass of steel.

Tempering consists of reheating the hardened steel to a temperature far short of that to which it was raised before hardened. This heating may or may not be followed by rapid cooling.

Annealing, as applied to steel, consists in heating the mass to a temperature higher than that used for tempering, and allowing it to cool slowly.

This may be seen experimentally in the following manner: Three strips of steel of identical quality may be taken. It can be shown by bending one that it is soft, but if it is heated to redness and plunged in cold water it will become hard and will break on any attempt to bend it. The second strip may, after heating and rapid cooling, be again heated to about the melting-point of lead, when it will bend readily, and will spring back to a straight line when the bending force is removed. The third piece may be softened by being cooled slowly from a bright-red heat. This will bend easily and will remain distorted.

The metal has been singularly altered in its properties by comparatively simple treatment. And all these changes, it must be remembered, have been produced in a solid metal, to which nothing has been added, and from which no material has been taken away. The theory of the operation described above has been laboriously built up; its consideration introduces many questions of great interest both in the history of science and our knowledge of molecular physics.

Physical Properties of Metals.

Molecular Structure.—The physical aspects of metal are so pronounced as to render it difficult to abandon the old view that metals are sharply defined from other elements, and form a class by them-

selves. Like all other elements, metals are composed of atoms grouped in molecules. Any force that alters the relations of the atoms in molecules modifies the physical properties of the metals. Indeed, it would be easy to show that the physical constants of each metal vary with its degree of purity. The molecular grouping of metals is doubtless very varied, and little definite is known regarding the structural stability of most of them; but it may be assumed that it is not very great, as some metals split up into single atoms when they are volatilised, and most of them unite readily with chlorine and oxygen. Consequently, any mass of which the fundamental molecules are the constituent particles may practically be regarded as a single molecule. Two fundamental molecules must, however, be held to be capable of uniting to form complexes that have less power of cohering, and any circumstances tending to bring about the formation of such complexes would tend to make the material less tough. This may account for the extraordinary alteration in the properties of many metals produced by very small quantities of incompatible foreign matters.

Density.—The density of the metal is dependent on the intimacy of the contact between the molecules. It is dependent, therefore, on the crystalline structure, and is influenced by the temperature of the casting, by the rate of cooling, by mechanical treatment, by the purity of the metal. All metals, except bismuth, are lighter when molten than in the solid state. In the case of cast iron, which passes through a pasty state on solidification, the density is augmented by wire-drawing, hammering, and any other physical method of treatment in which a compressing stress is employed. Mere traction, however, may diminish the density by tending to develop cavities in the metal. Pressure on all sides of a piece of metal increases its density. A metal can only be compressed if the result of the application of pressure is to cause it to pass to an allotropic state—that is, denser than that which it originally possessed.

Fracture.—The appearance of the fractured surface of a metal depends partly on the nature of the metal and partly on the manner in which solidification occurred. Sudden cooling, to a great extent, prevents the formation of crystals, while slow cooling facilitates their development. Long, continual hammering, frequent vibrations, and intense cold will produce the latter result. Any condition that affects either the cohesion or the crystalline structure of a metal affects its fracture.

Malleability.—This is a property of permanently extending in

all directions, without rupture, through pressure produced by slow stress or by impact. As a rule, crystalline metals are not malleable, and any circumstances that tend to produce crystallisation must affect the malleability. Thus, in nearly all metals, the malleability becomes impaired when they are subjected to rolling or long-continued hammering. But this property may be regained by annealing, which consists in raising the metal to a high temperature and allowing to cool, either rapidly or slowly. At different temperatures metals behave in different ways.

Every malleable compound of iron, containing the ordinary elements of that metal, which is obtained either by the union of pasty masses of the iron or by any process involving fusion, and which cannot be hardened by an ordinary method, will be called by us "wrought iron."

Ductility is the property which enables metals to be drawn into wire. It generally decreases with an increase in temperature of the wire at the time of drawing; but there is no regular ratio between the two. Iron is less ductile at 100° C. and more ductile at 200° C. than it is at 0° C.

Tenacity is the property possessed by metals, in varying degrees, of resisting the separation of their molecules by the action of a tensile stress.

Toughness is the property of resisting the separation of the molecules after the limit of elasticity has been passed.

Hardness is the resistance offered by the molecules of a substance to their separation by the penetrating action of another substance. Great differences are observable between the hardness of various metals.

Elasticity is the power a body possesses of resuming its original form after the removal of an external force which has produced a change in that form. The point at which the elasticity and the applied stress exactly counterbalance each other is termed the "limit of elasticity." If the applied stress were then removed, the material acted upon would resume its original form. If, however, the stress were increased the change in form would become permanent, and permanent set would be effected. Within the limit of elasticity, a uniform rod of metal lengthens or shortens equally under equal additions of stress. If this were the case beyond that limit it is obvious that this would stretch the bar to twice its original length, or shorten it to zero. This stress, expressed in pounds or tons for a bar of 1-inch square cross-section, is termed the modulus of elasticity.

The ultimate tensile strength or maximum stress the material can sustain without rupture, the limit of elasticity, and the breaking stress are the points which usually have to be determined, and these alone will be considered here. In testing a piece of metal, the first point to be determined is the limit of elasticity. When a metal, such as a piece of iron or steel, is submitted to stress by pulling its ends in opposite directions, it stretches uniformly throughout its length. There is, however, in such a solid a limit in the application of the stress up to which the metal, if released, will return to its normal length. This point is the limit of elasticity.

Influence of Foreign Elements on the Strength of Metals.—The influence of chemical compositions on the mechanical properties of metals is of great importance. The influence of foreign elements is best shown in the case of iron. The properties of this metal are absolutely changed by the presence of a few tenths per cent. of carbon. Phosphorus and silicon produce very dangerous impurities in iron. It is difficult to estimate the influence of silicon. It is known that its addition to molten steel is useful, as it prevents the formation of blowholes in the solidifying mass.

The colour of metals is influenced by their purity. Thus, iron becomes white by the admixture of carbon, silicon, sulphur, and phosphorus. All metals are fusible. When strongly heated, they pass from a brownish-red to a clear red colour, which gradually increases in luminosity and transparency to a dazzling white. On solidifying from a molten state, metals frequently exhibit effervescences due to the expulsion of absorbed gases. This expulsion, before solidification, causes a sudden outburst of metal through the surface. When it passes from the liquid to the solid state, it either does so suddenly, or it passes through an intermediate pasty stage. This fact is occasionally of great metallurgical importance.

On solidification after melting, metals usually crystallise. The crystallisation of metals is of great importance, as the formation of crystals, due to continued vibration, intense cold, sudden alterations of temperature, or the presence of impurities, may render a metal absolutely useless. Welding is the property, possessed by metals which, on cooling from the molten state, pass through a plastic stage before becoming perfectly solid, of being joined together by the cohesion of the molecules introduced by the application of an extraneous force, such as hammering. This property is exhibited in a marked degree by iron and platinum at a white heat.

All steel is iron, differing only in containing a larger percentage of carbon, usually with a small quantity of silicon and manganese,

and often a small percentage of some other metal. What is known as mild steel is a product that stands between wrought iron and the hardest steel, as that used for making cutting tools. This mild steel has largely taken the place of wrought iron and is used in the construction of steel buildings. Pure iron is a soft, greyish-white metal, very ductile and malleable, and highly tenacious. This is generally used as welding iron. After fusion, pure iron exhibits a crystalline scaly fracture. It is softer than wrought iron, and is not affected by heating to redness and quenching in cold water. It is highly magnetic, and welds readily. Its specific heat is 0·113 and its specific gravity 7·675. It melts to a lower temperature than platinum, about 1,600° C. In mass it is unaffected by dry or moist air, and more so in oxygen, yielding a scaly coating of oxide. When molten, it dissolves or occludes various gases in considerable quantities. Hydrogen, carbon monoxide, and nitrogen are thus taken up and given out on cooling.

The above physical properties are present in a greater or less degree in cast or wrought iron and steel, the extent to which they are modified depending on the purity of the substance. These bodies consist of iron containing varying proportions of carbon, silicon, manganese, sulphur, phosphorus, etc. The main difference between the properties of cast and wrought iron and steel are due to the presence of carbon in the metal, depending on the amount and the manner in which it exists in the iron. The maximum amount of carbon taken up by pure iron is stated to be 0·475 per cent. In cast iron containing manganese, a little over 5 per cent. may be present. Steel may contain up to 1·8 per cent., while the carbon in wrought iron seldom exceeds 0·25 per cent. and may fall as low as 0·05 per cent.

The designation of steel was formerly confined to those varieties of iron which could be hardened by heating to redness and plunging in cold water. The introduction of the Bessemer process marked a new era. The metal produced by that process lacks the fibrous character associated with wrought iron and partakes more or less of the character of steel. Varieties possessing more than 0·3 per cent. of carbon sensibly harden when treated in the same manner as steel. Some steels are even softer than wrought iron. Since the hardening property is dependent on the amount of carbon contained, a classification based on the percentage of that element is most convenient. Steel containing less than 0·5 per cent. is classed as mild steel. The different nature of the metals may be shown by the use of such titles as Bessemer, Siemens, or open-hearth steel. Some

of these contain as little as 0·08 per cent. of carbon—less than is often present in wrought iron. (This is the easiest of all steels to weld, but very little of it is manufactured, not being the usual standard.) They differ from wrought iron in being devoid of fibre, more homogeneous, and, unlike it, are obtained in a state of fusion.

The fracture of steel becomes finer the larger proportion of carbon present, but it is affected by such treatment as hammering.

Cold steel of hard temper breaks with a clear, uniform, grey, fine, granular fracture. After hardening, the colour is somewhat whiter. It is very malleable, but requires working more carefully and at a lower temperature than wrought iron. Steel containing less than 1·25 per cent. of carbon can be welded, but at a lower temperature than wrought iron, or the steel will be burnt. To render the surfaces clean at the lower heat, borax mixed with one-tenth of its weight of sal ammoniac should be employed to dissolve the scale.

The specific gravity of steel varies from 7·624 to 7·813. The melting-point varies with the proportion of carbon. The softest melts a little below 1,600° C. The tenacity varies from 22 tons in mild steel to 70 tons in steel of hard temper. The elasticity exceeds that of wrought iron, while the ductility is equal to the best qualities of that substance. The mild varieties suffer an elongation and diminution in area when subject to a stretching force greater than wrought iron. The elongation of the harder varieties is much less, but the elastic limit is high. Mild steels, when being welded and becoming molten at the weld, are liable to "bod." This is due to the disengagement of dissolved gases, mainly H, N, and CO, which are given up as the metal cools off. The bubbles of the gas cause the metal to be honeycombed and vascular.

Tenacity of metal is determined by straining a piece of metal of known dimensions, and observing the amount of force necessary to fracture it. Elongation, the extent to which a metal elongates prior to fracture, is a matter of greatest importance. Tough ductile metals show a considerable increase in length; hard, brittle metals elongate but little. Important evidence as to the working qualities of the material and efficiency of the weld is furnished. To determine the elongation, the test-piece is measured between the points at which it is gripped before and after straining till fractured (it is usual to put two marks on the test-piece for measuring), and the increase is stated in percentage of the original length. Thus a 10-inch test-piece of boiler steel measured 12·5 inches after fracture —*i.e.*, 2·5 inches over 10 inches, or 25 per cent. Elongation is

accompanied by a diminution in area of section. This is measured in order to determine whether the elongation was local or uniformly distributed. Sometimes the contraction in area is confined to the region of the fracture.

Some Difficulties in Welding.

Welds on mild steel, which apparently are the most easy to obtain, are in reality those which require the greatest study and skill on the part of the operator. The welding must be done to give the weld the mechanical properties approaching those of the metal to be welded. In cases where the process is applied without the knowledge of the technique, the strength of the metal and, above all, its elongation are considerably lowered. In short, the operation of welding can lower, at the line of joining, the principal qualities of mild steel, which are particularly required in metallic construction.

If the operator will go thoroughly through the chapter on iron and steel, he will learn much that will be of great assistance to him in his welding. One of the important things to remember in welding iron and steel is the formation of the oxide and its inclusion in the metal forming blowholes. It is to be noted that there is always a formation of oxide at the surface of the iron and steel melted under the action of the blowpipe. This oxide fuses before the metal, and is lighter. Therefore it rises to the surface of the metal when molten, and can be eliminated by passing the welding-rod in a horizontal position over the weld while the metal is molten. Steel and iron in a molten state dissolve 1·1 per cent. of oxide. This is always the case, and unless the operator has full knowledge of the technical and metallurgical points, he prevents the joints standing the stresses required. The technique of oxy-acetylene welding is very little known, and there are yet many problems to be discovered.

Many operators make the frequent mistake of interposing oxide in the weld. In nearly all these cases this is caused by burning of the weld, when an excess of oxygen is used, the flame held on the weld too long, and too large a surface liquid. It causes the weld to become "cinderised." In the melting period of the weld the suspended particles are no doubt due to the spitting of the metal as it fuses, but the origin of the oxide when the molten metal is covered with the slag is less certain. It may possibly be due to the presence of iron vapour in numerous bubbles of carbon monoxide formed throughout the molten weld; or probably to the spurting of the molten metal. The oxide defuses in the molten metal, and reaction takes place with the carbon and manganese and reduces their

strength. The dissolving of the gases may be given up, if the operators take care, when the metal is molten, to allow these gases to escape, and to make good solid welds.

One fault, of which many operators are guilty, is to use a too high-powered blowpipe, or to use too high pressure of oxygen, which causes an over-fierce flame. Consequently the metal has not time to get thoroughly hot before it begins to become liquid. Only just the surface is "swilled," and the underneath layer is not anywhere near the welding-point. This is the cause of many defective welds in which there is adhesion and oxide is interposed in the weld.

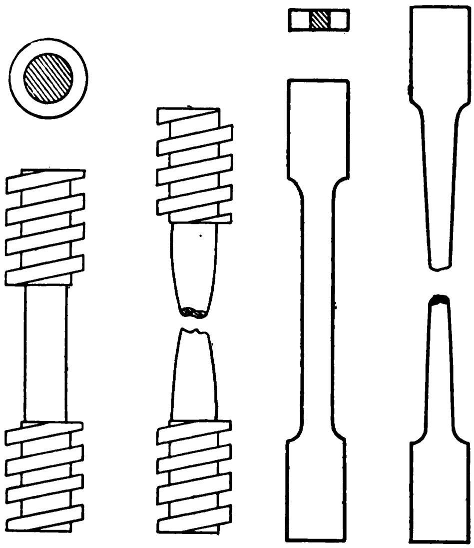


FIG. 61.—TENSIONAL TESTS, WELDED FLAT AND BARS.

This can be avoided if the proper-sized blowpipe is used, and the pressure of oxygen is that prescribed by the makers of the blowpipe, and no more. Then the weld must be proceeded with at a moderate speed, giving time for the edges of the article to melt thoroughly into a thick liquid form. Then the feeding-rod must be added and the weld filled up. The blowpipe must not be allowed to remain on the metal after it has been melted (and the tip must be kept about $\frac{3}{16}$ inch from the metal that is being welded) as it burns the metal after the first melting. If the metal gets too hot, it becomes too liquid and is burnt, and the carbon and other elements are partly destroyed, thereby reducing the strength of the weld considerably.

The point of the molten metal should be just a thick liquid, and should never be made hotter or thinner liquid, which causes oxidation and swilling.

The author would draw attention again to his previous remarks as to operators testing their work from time to time. Leading engineers, through so many past failures, and so many bad and defective welds, are not very favourable to allowing oxy-acetylene welding to be done on anything that has to stand any great stresses. Therefore operators should, without fail, make repeated tests from sample welded joints, as outlined in previous chapters. In addition to the tests explained, tensional, distortional, and other mechanical tests can be made, and will greatly assist operators in becoming efficient. These latter tests many schools would be glad to make on their behalf.

Blowpipes must be the best, if good welding is required. The previous chapter on the subject has laid this down; a further paragraph will help to emphasise their importance. Absolutely the best blowpipe must be procured, irrespective of cost. In the selection the following points should be considered: The blowpipe must have a constant clear flame with a distinct white cone, as large as possible and sharp-edged; must be easy of regulation; must not back-fire. There must be a proper mixture of the gases at the nozzle outlet, and at the correct pressure specified by makers, and no more. There must be no excess of acetylene (which carbonises), no excess of oxygen (which oxidises). The latter in excess is most dangerous. In no case must a hard or steel wire be used for cleaning out the blowpipe nozzle. A piece of copper wire would suit. If the nozzle of the blowpipe is only minutely enlarged, it causes disarrangement, and the blowpipe does not work satisfactorily.

Welding-rods for use on iron and steel are composed of pure iron in the form of wire, in the various sizes for the thickness of metal welds. By using a pure iron rod, the line of weld will also be pure (providing the welding has not been oxidised). All metallurgists are fighting against the inclusion of phosphorus, sulphur, and silicon in the manufacturing of steel and iron; therefore operators must also fight against allowing these impurities to find their way into a weld. A good flux for iron and steel is as follows:

Borax	3 parts	Melt in an earthenware vessel.
Colophony	2 ,,	
Pulverised glass ..	3 ,,	
Steel filings	2 ,,	
Carbonate of potash	1 part	
Hard soap powder ..	1 ,,	

One cannot be too particular in preventing these impurities in the welding line. None but the purest rods must be employed. They are to be got if the price is paid. One must not expect to obtain pure charcoal wire without paying for the purity. The extra cost is saved in many ways. The welding is faster, very much stronger, and almost free from oxide. There is no going over the weld twice, and no burning, as it melts freely. Finally, the weld is neater.

CHAPTER XXI

CAST IRON

CAST iron is the cheapest and most abundant form in which metal is met with in commerce. It is fusible at a temperature which can readily be attained; and, as it receives remarkably clean and exact impressions of a mould, it can be cheaply produced, even in very intricate forms. Its tensile strength, varying from an average of about 7 tons per square inch in common castings to upwards of 15 tons with special mixtures, is ample for many purposes. Its crushing strength is greater than any other material, reaching a maximum of about 100 tons per square inch. Being protected by a skin, cast iron resists atmospheric influences better than wrought iron or steel, while, for wearing surfaces for machinery, nothing is superior to cast iron on cast iron as sufficient area is provided.

Castings are much more easily and cheaply produced than forgings, so that the latter are only employed where special requirements or strength and ductility render their adoption necessary. As compared with steel castings, the advantages of cast iron for ordinary uses include not only the cheapness of the original material, but also the diminished cost in the preparation of the moulds, the smaller loss in casting, and the saving of expense and the time required for annealing, which is necessary for steel, but not for cast iron. Iron castings can, therefore, be prepared to meet a pressing emergency, while their fine surfaces, sharp edges, and pleasing appearance recommend them for general use. It must be noted that, in the welding of castings, one must not go over the weld twice, as it has an oxidising effect on remelting, and the portion of the silicon is diminished, while the sulphur is at the same time absorbed from the blowpipe gases. The natural effect of these changes is shown in the condition of the carbon, which, instead of being almost wholly graphitic, is all combined, thus producing a hard, white iron, deficient in tenacity, and brittle. The physical effects produced when cast iron is remelted are thus merely indications of chemical changes which have taken place in the material, whilst the nature of these changes will vary with the composition of the iron employed.

Effect of Size and Shape.—The strength and solidity of a casting are affected by the bulk of metal employed, and by the form of the casting made. When the metal cools in a mould, a crystalline is developed, the crystals forming at right angles to the cooling surface. If this cooling surface be curved, the crystals interlace, so as to yield a strong uniform structure, while, on the other hand, whenever a sharp change of curvature takes place, a plane of weakness is developed.

Shrinkage of Cast Iron.—Although cast iron, especially when very grey, expands at the moment of solidification, the subsequent cooling

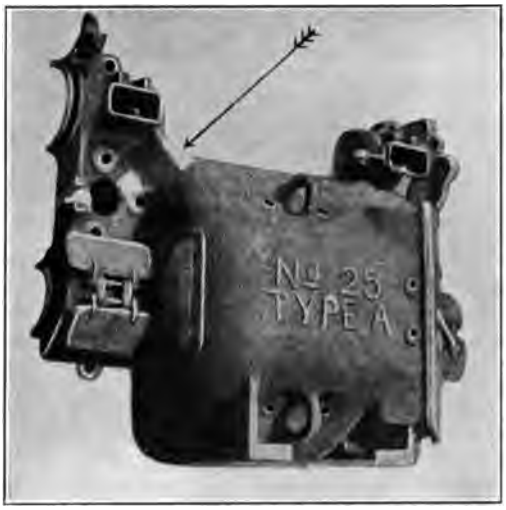


FIG. 62.—TRAMWAY GEAR CASE, OUTSIDE BEARING BROKEN OFF, SUCCESSFULLY WELDED.

from a red heat to the ordinary temperature leads to a still greater contraction. The shrinkage of castings is, however, by no means a constant quality, but varies with the proportions of the castings and with the character of the metal used.

Hardness of Iron.—The hardness or softness of cast iron is, in many instances, of the greatest importance, as the metal has to be turned, planed, filed, or otherwise worked with tools. When cast iron has to be turned or otherwise worked, the hardness is of considerable importance, while in some cases smoothness of surface and general perfection of the casting are of the utmost moment. Hard cast iron is brittle, deficient alike in crushing, transverse, and tensile strength, and seldom gives good clean castings.

When cast iron cools from fusion, the carbon may remain uniformly distributed through the mass—combined carbon—or a portion of it may separate out in scales resembling graphite. The extent to which separation occurs depends on the rate of cooling and the quality of the metal. Slow cooling, and the presence of silicon and aluminium in the metal, favour the separation, while manganese retards it.

FIG. 63.—PRESS FRAME BROKEN ON ONE SIDE, AND PATCHED WITH TWO 2-INCH BOLTS.
Bolts failed and welding was necessary.

When rapidly cooled, nearly all the carbon remains in the combined form.

Combined carbon hardens the metal, lowers its melting-point, destroys its malleability and welding power, and tends to make it brittle. The extent to which these effects are produced depends on the amount. In white cast iron containing as much as 3 per cent., the metal is brittle, breaks with a silvery-white fracture, melts more readily, and passes through a pasty stage in fusing. It is extremely hard, and this property is permanent. In steel for cutting instruments, the amount varies from 0·5 to 1·5 per cent. The hardness and fusibility are increased, the malleability and the welding power reduced, in proportion to the amount of carbon present.

FIG. 64.—PRESS FRAME WELDED AT COST OF £9 7s. 6d. WELD 3 FEET LONG AND 1 INCH THICK.
In use for the past two and a half years.

Graphitic carbon is met only in cast iron, and occasionally in steel. It reduces the strength of the metal by interposition between the particles, but does not affect the grains of the irons themselves. The generalisation above as to combined and free carbon only expresses part of the truth. When white cast irons, free from manganese, are heated for a long period,

at a high temperature, but below fusion, embedded in red hematite, the characteristic brittleness is lost, and they become more or less malleable.

In connection with the influence of cooling, cast iron obeys the laws which govern other solutions, for it is well known that slow cooling assists the production of crystals, and leads to the production of larger size, while with rapid cooling both solvent and substance dissolved may solidify together. In a similar manner slow cooling tends to produce graphitic carbon, and the slower the cooling the larger the flakes of graphite which separate. Some kinds of white iron may thus be rendered grey by slow cooling, while some kinds of grey iron may be made perfectly white by rapid cooling or "chilling."

That the carbon which exists in grey iron is in the graphitic form can be proved by many simple tests. Thus, if finely divided white iron be rubbed between the fingers, it is clean to the touch, while grey iron produces a smooth black coaling on the skin, exactly like that due to plumbago. It has been shown that nearly pure graphite can be separated from grey iron.

All cast irons contain silicon, in quantities varying in ordinary cases from under 0·5 to over 4 per cent. A small addition of silicon eliminates blowholes, and produces sound castings. As soon as the metal is sound, with the least graphite, the greatest crushing strength is obtained. This condition also gives the maximum density. The further addition of silicon leads to graphitic formation, diminishes the brittleness, and gives the greatest transverse and tensile strength. White iron shrinks during solidification more than grey iron, while highly siliceous iron shrinks still more than white. Hence, on adding silicon to white iron, the shrinkage is diminished; but an excess of silicon, on the other hand, leads to increased shrinkage. Shrinkage appears closely to follow the hardness of cast iron, hard irons almost invariably shrinking most; and as hardness and shrinkage depend upon the proportion of carbon, they may be regulated by a suitable addition of silicon.

Cast iron is a granular and crystalline compound of iron and carbon, more or less mixed with uncombined carbon in the form of graphite, but never contains more than 5 per cent. It is harder than pure iron, most brittle, and not so tough. The modes of combination of the carbon with the metal, as well as the nature and proportion of foreign matters, such as silicon, aluminium, sulphur, phosphorus, and manganese, determine the infinitely varying qualities according to the colour, degree of fusibility, hardness, tenacity,

and so on. All cast irons are not available for foundry purposes. In grey cast iron the carbon is mechanically interspersed in small black specks among the lighter particles of metals, the fracture being a dark grey colour, and being of granular or scaly crystalline character. Grey iron is much softer and tougher than white iron, and may be filed and turned.

In white cast iron the greater part of the carbon is present in the form of a chemical combination—carbide of iron—and white iron is very brittle, and can neither be turned in a lathe nor filed. Grey cast iron requires a higher degree of heat before it commences to fuse, but becomes very liquid at a sufficiently high temperature. It is important to remember this point when castings are being welded, especially when inclined from the horizontal, as the metal would run away from the weld. White cast iron is not so easy to weld. It does not flow well, is rather pasty in consistence, and scintillates as it flows in the molten state. White cast iron is silvery-white, either granular or crystalline, difficult to melt, brittle, and excessively hard. It is a homogeneous chemical compound of iron with from 2 to 4 per cent. of carbon. Granular cast iron can be converted into grey cast iron by fusion and slow cooling, whilst grey cast iron can be converted into granular white cast iron by fusion and sudden cooling. Crystalline white iron is harder and more brittle than granular, and is not capable of being converted into grey cast iron. Grey cast iron contains about 1 per cent., or less, of carbon in chemical combination with the iron, and from 1 to 4 per cent. of carbon in the state of graphite in mechanical mixture. The larger the proportion of graphite the weaker and more pliable is the iron.

The following remarks upon some points already described may aid in roughly estimating the quality of cast iron.

When the colour is uniform dark grey, the iron is tough, providing there is also high metallic lustre. If there be no metallic lustre the iron will be easily crumbled. The weakest sort of cast iron is where the fracture is of dark colour, mottled, and without lustre. The iron may be accounted hard, tenacious, and stiff when the colour of the fracture is lightest grey, with a high metallic lustre. When the colour is light grey, without metallic lustre, the iron is hard and brittle. When the colour is dull white, the iron is still more hard and brittle than in the last case. When the fracture is greyish-white, interspersed with small radiating crystals, the iron is of the extreme degree of hardness and brittleness.

When cast iron is dissolved in muriate of lime or muriate of mag-

nesia, the specific gravity is reduced to 2·155. Most of the iron is removed, and the remainder consists of graphite with the impurities of cast iron. The soft grey iron yields to the file after the outer crust has been removed. The quality of the iron in a melted state is really judged by the practised eye from the nature of the agitated aspect of its surface. The mass of fluid seems to undergo a circulation within itself, having the appearance of ever-varying network.

When this network is minutely subdivided, it indicates soft iron. If, on the other hand, crystals be thrown up in convolutions, the quality of the metal must be hard.

One of the most important points in the welding of cast iron is not to go over the weld twice, as each time any part is melted more than once, the graphite burns out and leaves white iron, which is hard and brittle. One must remember that every additional melting of cast iron injures, or is likely to injure, its quality as a structural material by the addition of foreign substances. These reduce the value of the coefficient of resistance at rupture and may, or may not, reduce that of ultimate extension. That is, the metal by remelting becomes weaker, and may become more brittle.

The numerous failures which puzzle operators in the welding of cast-iron articles are often due to lack of knowledge. They have not made themselves acquainted with the metal they are welding. It is a *sine qua non* that, if they are to become proficient operators, they must have the necessary metallurgical knowledge, so as to know exactly what are the constituents of the metal being welded. The state of the carbon in the metals depends on whether welds are of grey iron. It is necessary for every welder to study thoroughly the causes that facilitate or prevent the precipitation of the carbon in the form of graphite. The rapid cooling of the molten metal in fusion will bring about the combination of the carbon and the iron. This forms white iron, which is hard and brittle, and cannot be machined or filed.

Welding of cast iron is a simple process, and with an experienced man, who has knowledge—metallurgical and chemical—of the article he has to weld, failure is impossible. The repair on the line of welding is generally of a superior quality to the rest of the casting, owing to the metal added being purer and the weld well carried out and free from blowholes. Cast iron consists of metallic iron, together with at least 1·5 per cent. of carbon. It also contains sulphur, silicon, phosphorus, manganese, and other elements in greater or less proportion; but these, as indicated above, may be regarded as impurities. The proportion of elements other than

iron is usually about 7 per cent. of the total weight. Cast iron is fusible at a temperature of about 1,200° C. When cold it is hard and brittle. It is not malleable or ductile, nor can it be hardened or tempered like ordinary carbon steel. Cast iron, when fused, consists of saturated, or nearly saturated, solution of carbon in iron. The amount of carbon which molten iron can thus dissolve is about 3½ per cent. of its own weight, though the solubility is largely influenced by the presence of other elements. As long as iron containing some 3 per cent. of carbon remains in the fused condition, the composition is uniform throughout, and the carbon has no tendency to separate from the metal except with very grey iron. In this case a layer of graphite may be formed. But when molten cast iron is cooled to a temperature at which it begins to solidify, it may either retain the carbon and solidify in a relatively homogeneous form, called white iron, or may, in solidifying, precipitate the greater part of the carbon in the form of small scales of graphite which, being entangled by, and uniformly distributed through, the iron, imparts to it a somewhat spongy nature, and produces the dark colour and soft character met with in grey iron. The condition which the carbon assumes on the solidification of the mass is dependent partly on the rate of cooling, and still more on the nature and quantity of the associated elements.

In the early stages of the oxy-acetylene process it was generally considered that cast iron and cast steel could not be welded by this process. The author, over fifteen years ago, welded castings by this process nearly daily, and executed some very important castings with success. At this period he found out how valuable and necessary was the preheating furnace for counteracting the phenomenon of expansion and contraction. Since then it has been recognised that the only way of getting satisfactory castings welded is by the use of a heating furnace, both for preheating before welding and for annealing after welding, allowing the casting to cool very slowly. Failure is almost impossible if this is carried out, provided the weld has been properly executed.

Of late years operators and employers have been getting more enlightened on welding processes, and most are now providing these necessary appliances. Also all operators are now taking technical courses at the various schools. Cast iron, in the author's opinion, is the easiest of all metals to weld. With a little practice, combined with technical knowledge, operators are soon able to do intricate jobs; and the welded part, if done well, is generally better than the other parts of the casting, because the material added by the weld-

ing-rod is purer in its mixture, and should thus be better metal. Cast iron cannot be forged, but articles are cast. They are not malleable or ductile. The majority of castings in iron should be capable of being worked—that is, they must be soft metal when finished and able to be filed or machined. The metal of grey castings is usually grey iron. The description at the beginning of this article should be studied thoroughly. One must remember that the rapid cooling of the metal in fusion brings about the combination of the carbon and the iron, which means the formation of white iron. Slow cooling and reheating bring about precipitation of the carbon and grey iron.

The melting-point of cast iron is 1,200° C., but its oxide melts at 1,350° C. This is an important point, and in melting, the oxide usually flows on the top of the weld, where it can be removed either by a flux or (if the welder be experienced) by the welding-rod, scraping it over the surface horizontally. If the flame is held too long on the casting after the metal is molten, the metal burns and oxidises, the silicon is volatilised, the carbon decarbonised, and the weld will be hard and cannot be machined or filed. When cast-iron articles are welded the welding flame causes, to a certain extent, a volatilisation of the silicon, which is contained in the metal in proportion from 0·5 to 4 per cent., generally about 2 per cent. If this is burnt out, it is necessary to replace the loss, which is done by the welding-rod, which should contain 5 per cent. of silicon. Therefore, as welding takes place, the rod with the increased percentage of silicon gives back to the casting the percentage that has been volatilised out. This material usually leaves the welded line soft, so that it may be machined or filed.

Of the difficulties experienced, the first is the expansion and contraction. Owing to the metal being non-ductile, and devoid of those elements for elongation and elasticity, castings are difficult to handle. The only remedy is preheating in a furnace, and annealing after welding.

The second difficulty is to prevent the line of welding becoming hard. To stop this the weld must be made at the first trial, and must not be gone over a second time. The welding must also be sharp, as, if the blowpipe is kept on too long, it is burnt and the weld hard.

Thirdly, the temperature of the casting must be brought up in the furnace to between 850° and 900° C. before any welding takes place. If it is lifted from the furnace to the welding table, it must be done quickly, and quickly welded, and returned to the

annealing furnace before the heat of the casting gets below the 850° C. Below this temperature the forces of expansion and contraction begin to come into action, and internal strains will at once be set up, which may, in a few minutes, if the temperature is much below 850° C., crack or fracture in the casting; it is not necessary in the weld. In some cases, the internal strains remain in the castings without fracture, until the casting becomes quite cold, when the fracture from the release of the internal strains occurs.

After welding, and putting the casting into the furnace, it must at once be seen to that the temperature of the furnace is raised (if it is not already raised as it should be) to 950° C. This is so that the casting after welding can be raised to this heat quickly, to bring the parts of it up to one heat, since the part that had been welded was very much hotter than the part not welded. Thus one can stop uneven contraction when the casting is being cooled off. After the heat has been raised to 950° C., which would not be long if the furnace is working as it ought to, the furnace must be cooled right down to cold before removing the casting.

Some illustrations of preheating and annealing are given in previous chapters relating to expansion and contraction. They should be carefully studied.

Fourthly come the difficulties of lack of penetration, bad joining, sinking of the surfaces, blowholes, and interposition of oxide. Lack of penetration is a frequent occurrence. There is, however, no justification for it, if operators will only go to the bottom of the weld in all cases. The blowpipe must be kept on the particular welding line, until such time as the bottom is melted. When the bottom is found at the starting-point, there should be no mistake about the line being continued from the bottom of the weld.

Interposition of oxide is a common occurrence, but it is one which can easily be avoided. It occurs through using an excess of oxygen, making the molten metal oxidised too liquid and too hot, and through being too long on welding and going over it more than once. The oxide forming through these errors is imprisoned in the metal. Therefore, it is not homogeneous, and the weld is defective. This will not come about if the operator will first of all bevel the joint where it has to be welded. When it is ready and heated, welding must take place at once by commencing on the bottom of the bevel. As soon as this is melted, add the welding-rod, previously heated, in the bevel, move the blowpipe forward with an elliptical sweep, keeping it close in the line of metal. Do not let the white tip touch the metal, but keep it about $\frac{1}{8}$ inch from it, and go steadily and

slowly forward, filling up the bevel uniformly with the feeding-rod until the end of the weld is reached. There must be no stoppage whatever, while welding the line prepared. If you stop, your weld will be hard and cannot be filed or machined. If it is done quickly, and filled in as the welding proceeds, with no stoppage, the weld will be a success, neat, strong, and easy to work.

If the article to be welded is a complete casting with a break, then it would be necessary to bevel the fracture on both sides before welding: such a case is a motor cylinder broken on the flanges. The one illustration below would require bevelling; and take care that the weld is thoroughly penetrated.

Welding-rods used for cast iron should be made more or less from good tough metal, with a fine granular structure, and free from impurities, especially manganese. They should be incorporated with silicon, in two grades, one to have 2·9 per cent. and the other to have 4·1 per cent. of silicon. The object of this grading is very important, as the one has a large granular structure, and the other has a fine granular structure. The latter would be used on heavy machinery work, and the former on smaller castings, such as motor-car cylinders, which are cast from fine granular material.

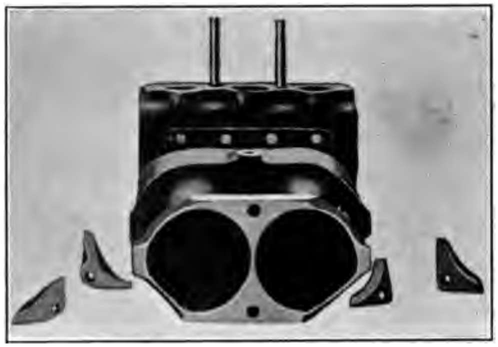


Fig. 65.—Two-Cylinder Motor Engine Broken.

All founders grade their metal in this manner. They do not use the same for both light and heavy castings. Therefore it is imperative that the welding-rods should be made in accordance with the general specifications of the general castings; and they should be very smooth and regular in thickness, which should be from $\frac{1}{8}$ inch diameter rising by $\frac{1}{16}$ inch diameter to $\frac{1}{2}$ inch diameter.

They should be 20 inches long, and should be all sand-blasted, after they are cast. This is an important point. Otherwise the rods will be all rough and covered with sand, which is very detrimental to the weld. No welding-rods must be used which have not had the moulding sand removed; nor must welding-rods be used that have been cast in solid moulds, as they would be chilled and hard.

It is not agreed in the welding trade that fluxes are necessary for the oxy-acetylene welding of cast iron. The author does not advise the use of any flux whatever, in general. But there are a few cases in which a flux is of great assistance—*e.g.*, where castings are old, or are full of sand and slag. This will only occur where cheap castings are made. The method of using the flux is to dip the end of the rod into flux, which should be near to hand and to the rod being heated. The flux must not be thrown into the molten weld, as too much would make the weld hard, so that it could not be worked.

The illustration (Fig. 67) shows a good test of cast-iron welding —a water pump accidentally broken while being worked in the shop. It was welded in thirty-six minutes.

FIG. 66.—TWO CYLINDERS WELDED COMPLETE.

The method of execution was as follows: The casting was first bevelled with a diamond-point chisel, the metal being $\frac{5}{16}$ inch thick. The gas furnace had already been lit. The casting was placed on a sliding grid, which fitted on the sides of the furnace. This sliding grid, with casting placed and fixed in position, was lifted by a small swinging hand-crane, hoisted by a rope, and swung round to the furnace, when the grid was pushed into the furnace. The casting was covered with an asbestos "shawl," and the door closed. The temperature was then at 550° C. Another burner was lit, and the temperature rose to 950° C. in thirty-five minutes Half the burners were put out, and the sliding grid, with the casting still fixed, was lifted by the crane and placed on the welding table. The blowpipe, already in position, was lit, and the welding started, and was continued without interruption or without going over any part of the weld twice. The grid was then attached to the crane, which swung the casting back to the furnace. The door was closed and the two burners lit till the temperature (then 800° C.) was raised to 950° C. (this occupied only thirty-six minutes from the time the furnace door opened to take it out till the door closed for annealing). Then the burners were turned right out, and the casting was allowed to cool slowly overnight. The result was a first-class job, strong, well-annealed, and with no distortion.

The field for welding such castings is enormous. The demand is greater than the supply. There are few operators able to do all jobs as they come along. If they had scientific and technical training, which should be followed up with practical work, they would become proficient, and would be able to do any class of work. The possibilities of welding broken castings are great, and almost any repair can be done. A few articles here are shown which can be and have been welded by this process. Good jobs can always be done if

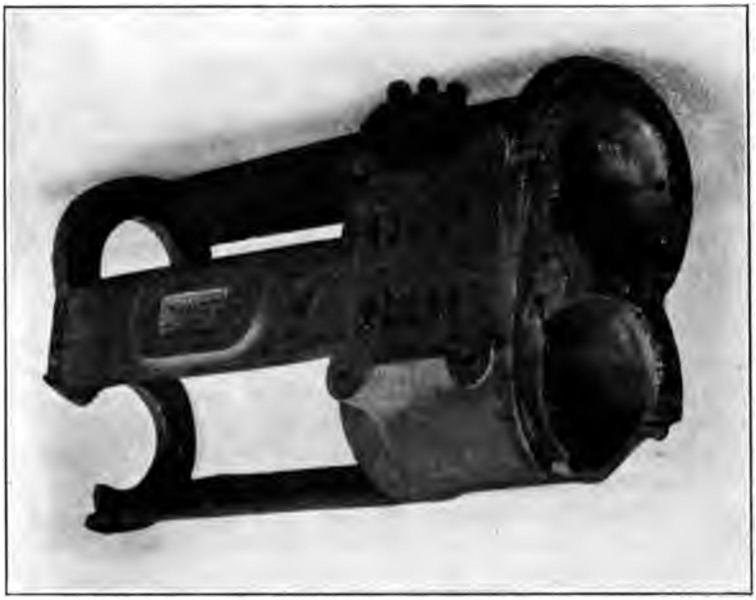


FIG. 67.—BROKEN TWO-CYLINDER WATER PUMP.

operators carry out carefully the instructions given. I may repeat that in all cast-iron weldings, if success is to be attained, the article must first be prepared, must be preheated (free from air) to a temperature of 950° C., welded with the purest welding-rod, returned to the annealing furnace when the casting gets down to 850° C., whether the casting is finished or not, and, if it is necessary to weld further, must be brought up again to a temperature of 950° C. It can be taken out for welding, and afterwards returned to the furnace and allowed to cool slowly, free from air.

CHAPTER XXII

DISSOLVED ACETYLENE

DISSOLVED acetylene, sometimes called high-pressure acetylene, is being greatly used, owing to its convenience, the purity of its acetylene, the equal pressure and proper mixture of the two gases. the regularity of flame, the absence of oxidising or carbonising, the well-maintained sharp cone at the tip, and the continuous welding till the cylinder is empty.

Dissolved acetylene is acetylene in its purest form, compressed after purification into cylinders containing an absorbent material. The gas is first generated in an ordinary carbide-to-water type in which the carbide falls in large volumes of water in order to prevent overheating of the gas and to maintain within the generator a temperature considerably below that at which local polymerisation of the gas can occur. Otherwise the heat of dissociation, which represents 1·65 per cent. of the total heating value of the gas, and is responsible for the phenomenal heating value of the acetylene flame, is liberated either wholly or in part during generation, and is therefore not available in the flame; in that case further local polymerisation takes place, and the tarry residues mix with the water and the gas and make the latter impure. The acetylene, after generation, must be treated by numerous processes in order to extract the impurities. These impurities are in three forms—gaseous, liquid, and solid. There is no single process capable of dealing effectively with the three. The gases must be treated with at least six processes of purification, two of which must be mechanical, four chemical. All chemicals must be incapable of producing overheating of the acetylene undergoing purification. Special precautions must, at all times, be maintained to preclude the possible admixture of air with the acetylene. All purifiers and the acetylene, after purification, should be tested twice daily in order to secure complete purification.

The acetylene is then compressed into cylinders already prepared with solvent material. The compressors used for this purpose are multiple stage compressors, with intermediate cooling between

each stage. The cylinders of the compressors must be water-jacketed, and the degree of compression in each stage must not be capable of raising the temperature in excess of 100° C.—that is, one-sixth of the critical temperature. The gas, after compression, and prior to entering the cylinders, must undergo mechanical separation for the extraction of final traces of moisture.

Cylinders in which dissolved acetylene is stored are made from the finest quality steel, and is cold-drawn to the shape of the cylinder from a flat piece of steel, whilst the bottom and walls are folded over one another and pressed together under a pressure of several tons per square inch. Only the finest and most ductile quality of steel would permit of cold-drawing for 44 inches in length. The cylinder walls, only $\frac{3}{16}$ inch thick, although only intended for use under a pressure of about 200 pounds per square inch, are made to stand a pressure of 1,000 pounds per square inch. As is well known, acetylene gases can only be stored under pressure with safety when dissolved in a solvent such as acetone, which must be absorbed by a porous material adapted to fill the space in the containing vessel.

FIG. 68.—PERFECT NEUTRAL FLAME.

When blowpipe is working properly, the length of the small white cone is as shown. In the patent "D.A." blowpipe, the numbers on the tip correspond to the consumption of acetylene in litres per hour.

Government regulations require that the porosity of the absorbent material in the container shall not exceed 80 per cent., and shall be homogeneous through the material without any free gas space. In the past it has been customary to employ, as the absorbent body granulated, solid material such as charcoal, or an animal filament, such as silk, but these substances are subject to certain disadvantages. Granulated charcoal and other solid materials tend to disintegrate into dust by attrition of the particles, if the container is subjected to repeated vibration or bumping. This disintegration creates free gas space and also dust particles, which are liable to blow forward with the gas and block the container valve or the nozzle of the blowpipe employed when the dissolved acetylene is used for welding. Silk, owing to its fibrous nature, does not disintegrate, but, on the other hand, it is not sufficiently resilient to obviate packing, and saturated with the liquid solvent and subjected to repeated vibration and bumping. The consequence is that free

gas space may be created after the container has once been packed to the prescribed porosity and put in use.

There has since been patented an improved method of storing compressed acetylene gas. This patent was taken out by Thomas Gaskel Allen, of London, July 27, 1916. The object of the invention is to provide a new type of filling material, superior to that used in the past. According to the material employed, it is sometimes known as " kapok " (Javanese fibre), or Indian kapok. One form suitable for the purpose of this invention is the *Eriodendron anfractuosum*, but the invention covers any suitable variety of kapok. Using this material, a much smaller weight than previously is necessary to obtain a porosity of 805 in the container.

Further, kapok has a tendency to swell when it absorbs the liquid solvent, thus precluding altogether the possibility of free gas space forming within the container after it has been once packed to the required porosity. On examination with the microscope, the central tube, filled with air, gives to fibres or kapok its very valuable lightness. The fibres are absolutely impermeable by water, owing to the presence of wax with which the filaments are coated. They will support from thirty to thirty-five times their own weight in water. Ordinary cork will only float five times its weight. This special fibre, when used as a filling material, cannot disintegrate into dust, no free gas space can be created by constant vibration, and no dust can pass through the blowpipe.

Dissolved acetylene compressed in cylinders provides a definite volume of acetylene of the highest purity, at a constant pressure, controlled by a regulator fixed on the oxygen cylinder valve. This, together with the oxygen in equal volumes and at equal pressures, gives a wide range for welding. The clear flame obtained is shown in Fig. 68.

The cone should not be allowed to touch the metal, but should be held so that the required heat is obtained without burning the work. When stopping the blowpipe, always turn off the oxygen first. This system has many advantages over the low-pressure process. The gas is always ready for use without waste of time in preparation, and when shut off it can be stored indefinitely without loss. It is handled with the greatest ease, and can be used in any position. The apparatus is cheap; the handling of carbide and water and the necessity of removal of residue are eliminated. There is no danger to the operator, and no bad smell, owing to the purity of the gas.

CHAPTER XXIII

CUTTING IRON AND STEEL

THE use of oxygen for cutting iron and steel is being developed enormously, and is being adopted everywhere. The method consists essentially in an ordinary blowpipe, with an additional passage through which an independent and separately controlled stream of oxygen is supplied at the discretion of the operator. This separate supply of oxygen may be discharged through the centre of the blowpipe, in which case the mixed gases employed for heating are conducted through an annulus surrounding it; or the supply may be brought in a passage immediately behind the heating flame.

The simple expedient of maintaining an independent heating jet in operation, whilst the cutter is travelling, renders the cutting operation continuous. It furnishes the quantity of additional heat necessary to render the oxide fluid, so that it can be blown away through the cut by the separate jet of oxygen. The cutting operation can be mastered by any intelligent workman in a few hours. The edge or surface of the plate at the point to be cut is heated by the mixed jet of oxygen and acetylene. When this spot has been brought to a state lower than the melting-point, a fine jet of oxygen is discharged upon it. This immediately produces combustion of the metal, with the resulting formation of the oxide. The jet of oxygen is made sufficiently strong to blow away this oxide in front of it, with the result that a clean, narrow cut is effected through the metal at a speed of travel which is comparable with hot sawing. The metal on each side of the cut is neither melted nor injured in any way, as the action proceeds too rapidly for the heat to spread. In fact, the edges present the sharp and purely metallic surface of a saw cut.

The cutting may be made to follow any desired lines, executing circles, curves, or profiles as desired, for which purposes guides and other mechanical contrivances are supplied. Special appliances are supplied for ensuring a steady movement of the cutting nozzle, a matter of considerable importance where neat and accurate work is desired. The process may be employed for cutting sections of any

thickness up to 16 or 20 inches. In metal cutting by oxygen, the melting-point of the metal should never be reached. The successful employment of oxygen for this purpose, therefore, depends on the melting-point of oxide being lower than that of the metal.

The cutters are made in several varieties. The British Oxygen Company are makers of the one illustrated below, which is a "universal"; it is a reliable article and is largely used.

Rubber tubing must be fixed at *O* and *H* respectively. The gases for heating are separately adjusted by valves *R* and *H*. These mixed gases are discharged through the passages *D*. The valve regulating the supply of oxygen for cutting is separately controlled by means of the thumb screw *Q* or the thumb lever valve *P*. The separate jet of oxygen for cutting is discharged through the passage *C*. *A* is an adjustable sliding guide, which can be

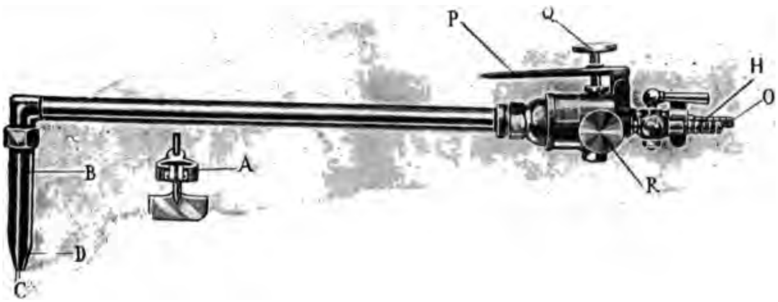


FIG. 69.—HAND-CUTTING BLOWPIPE.

attached to the cutter head at *B*, in order to maintain a uniform distance between the cutter and the work. There are two nozzles—one for cutting up to 6 inches thick, and a spare one to cut over 6 inches. The table on p. 137 gives the approximate results with various thicknesses, the consumption of oxygen, and lineal feet cut per hour, etc.

This is a very useful table. Operators can compare results from their own cutting by it.

Since the period in which oxygen was introduced the development has been rapid. Here, again, the war has brought this unique process into vast uses, which would have taken ten years of industrial work to attain.

The real theory of oxygen cutting of iron and steel was a very simple process, and was known for years before it became a commercial proposition. It was found in the chemical laboratory that if a thin strip of iron or steel is plunged into a jar of oxygen, after

being heated to redness, the iron ignites to incandescence and burns right away. This, then, is the equivalent to cutting steel by oxygen, as we shall see as we go along.

Thickness of Plate.	*Size of Cutting Nozzle.*	*Oxygen Pressure.*	*Consumption of Oxygen per Hour.*	*Feet of Metal Cut per Hour.*	*Consumption of Oxygen per Foot Cut.*
Inches.	*Inches.*				
$\frac{1}{4}$	$\frac{1}{32}$	24	48	65	0·75
$\frac{1}{2}$	$\frac{1}{32}$	28	60	60	1
$\frac{3}{4}$	$\frac{1}{32}$	32	75	50	1·5
1	$\frac{1}{16}$	32	88	40	3·2
$1\frac{1}{4}$	$\frac{1}{16}$	36	95	35	3·7
$1\frac{1}{2}$	$\frac{1}{16}$	39	105	30	3·5
2	$\frac{1}{16}$	45	125	25	5
3	$\frac{1}{16}$	52	180	20	9
4	$\frac{1}{16}$	58	300	20	15
5	$\frac{1}{16}$	65	420	20	21
6	$\frac{1}{16}$	70	432	18	24
8	$\frac{3}{32}$	80	504	18	28
9	$\frac{3}{32}$	95	510	17	30
11	$\frac{7}{64}$	100	620	13	48
12	$\frac{7}{64}$	125	650	13	50

Most metals oxidise under the action of the oxygen in the atmosphere, as is instanced by the rusting of iron exposed to the air. This is a form of oxide of iron. Upon the heating of the iron, the oxidation is very much more rapid and intense. Considering the method of cutting by a jet of oxygen, the object is to make the oxidation as intense as possible, so as to burn in the shortest time when in connection with the oxygen, and to obtain the narrowest cut possible. The oxidation takes place at the part which has previously been heated to redness, because at this temperature reaction takes place readily. The combustion of this part of the iron disengages heat, a portion of which is absorbed by the neighbouring part. This is sufficient to raise it to a red heat, so that it in turn burns, and this reaction is progressively propagated throughout the metal. The oxide formed has a much lower melting-point than that of the metal, and is detached, leaving the iron continually bare.

Highly carbonised steels, whose melting-points are appreciably lower than that of iron and in the neighbourhood of the oxide of the metal, do not lend themselves to cutting because the oxidation does not propagate itself; nor does cast iron, on account of the impossibility of eliminating the oxide mixed with the molten metal. Iron and steel are about the only metals that can be cut by the oxy-

acetylene process. This is owing to the oxide of iron and steel melting at a much lower temperature than the metal itself. Other metals, where the melting-point of the oxides and the metals are nearly equal to one another, cannot be cut by this process. The reason why iron and steel can be cut is because, when the metal is heated to redness, and oxygen impinges upon it, it is immediately oxidised, and the pressure of the oxygen blows the oxide away as it is formed, leaving a clean cut through the metal. Most of the non-ferrous metals cannot be cut by oxygen for the reason stated above, and also very high carbon steels do not lend themselves easily to cutting. They can be cut, but it is very difficult, and many failures occur. Nor does cast iron lend itself to cutting with an oxy-acetylene cutter.

Cutting by a jet of oxygen can only be applied to iron and steel in a continuous manner by contact with oxygen, for the reason that iron and steel oxidise very rapidly when heated to redness, and the oxide of iron formed by the impinging of the jet of oxygen combines and forms in a molten mass on the steel or iron plate; and, at the same time that the molten oxide is formed, the pressure of the oxygen blows the molten mass away, leaving a clear channel through the whole thickness of the plate. In order to make the cut continuous, it is necessary to maintain the steel plate at a red heat along the line of cutting. Taking into consideration that the plate absorbs a quantity of the heat by conducting it over the cold parts of the plate, the cutting pipe has to have a preheating flame, in addition to the jet of oxygen for blowing away the oxide as it is formed. The cutting pipe must be regulated for speed by the heating of the plate, and this heating must be continued as the cutting proceeds. It is not necessary to heat the plates to more than red heat if a clean cut is desired. By raising the temperature to a welding heat, cutting action is stopped, and the metal becomes blobbed and forms a clot of oxide on the top of the plate.

One must try to reduce the oxygen to a minimum by regulating the supply. It is not necessary to have high pressure or a large nozzle, except when cutting very thick stuff, because excess of oxygen means that the oxide will contain an excess of oxygen and the resulting oxide will be Fe_3O_4—*i.e.*, three of iron and four of oxygen. If the oxygen is correctly regulated and the pressure not too heavy, the cutting will be much more economical, and more lineal feet will result, with cleaner cuts. The oxide formed would be FeO—*i.e.*, one of iron and one of oxygen. The pressure of oxygen required to cut the various thicknesses must be carefully considered.

In many cases it is very indeterminate. What is desirable is the thinnest possible jet, with great length, capable of blowing the oxide away as it is formed, leaving the narrowest clean cut, and using oxygen at the very lowest pressure. The heating flame—its intensity and length, the distribution of heat—always influences the result, and its direction and distance are most important.

Also, the purity of the oxygen is most important. At 99 per cent. purity, the maximum lineal feet of cutting can be obtained; 95 to 96 per cent. of purity reduces the lineal cutting from 10 to 15 per cent. With 90 per cent. cutting will only be intermittent.

FIG. 70.—THE RADIOGRAPH CUTTING STEEL PLATE WITH THE OXY-ACETYLENE FLAME, AT SPEEDS VARYING FROM 18 INCHES TO 2 INCHES PER MINUTE ON PLATE FROM $\frac{1}{4}$ INCH TO 20 INCHES THICK.

It will be noted that practically any thickness can be cut, from the thinnest to 16 or even 20 inches thick. With thick plates machines are needed to guide the line of cutting. Fig. 70 illustrates cutting a large plate.

Where cutting has to be done by hand, care must be taken that the line of cutting is straight. In many cases, rollers are used to steady the cutter and to act as a guiding support. Operators must see that the heating flame and the delivery of the oxygen for cutting are regulated proportionally to the thickness of the plate to be cut. The pressure should be regulated at the reducing valve, and the minimum pressure must be used in all cutting operations, as a cleaner cut will be got. If a high pressure of oxygen is used

when cutting iron or steel, it spreads around the place where heating is taking place; hence it cools the surface, thereby retarding the cutting.

It is not necessary to have increased pressure of oxygen. Many welders think that the higher the oxygen pressure, the quicker and better. This is a fallacy. Pressures from 10 to 40 pounds are

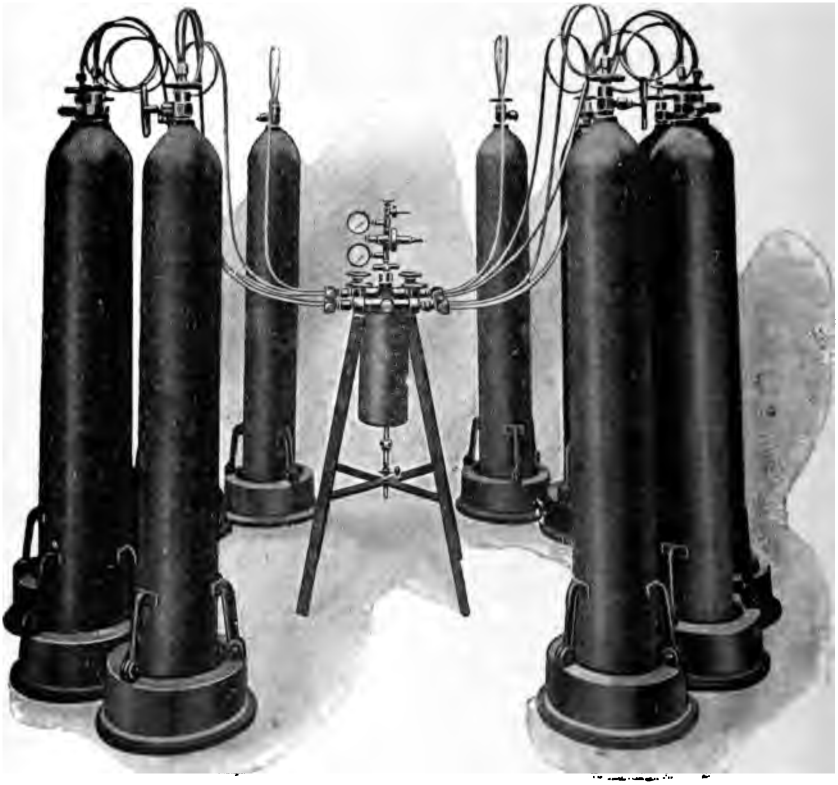


FIG. 71.—COUPLED CYLINDERS, FOR CONTINUOUS WORK.

ample for most commercial thicknesses, and more cutting and neater work will be obtained if the oxygen is kept at these pressures. Further, the saving in oxygen is large—quite 20 per cent. It is not pressure that is needed, but volume. When cutting a great thickness, several cylinders are brought into requisition and coupled up together. From this one gets a large volume; but it only needs a medium pressure. The above illustration shows these coupled by cylinders.

This arrangement enables three cylinders at a time to be detached when empty, and replaced with full ones, while any or all of the others are feeding oxygen to the regulator fixed on the tripod stand in the centre.

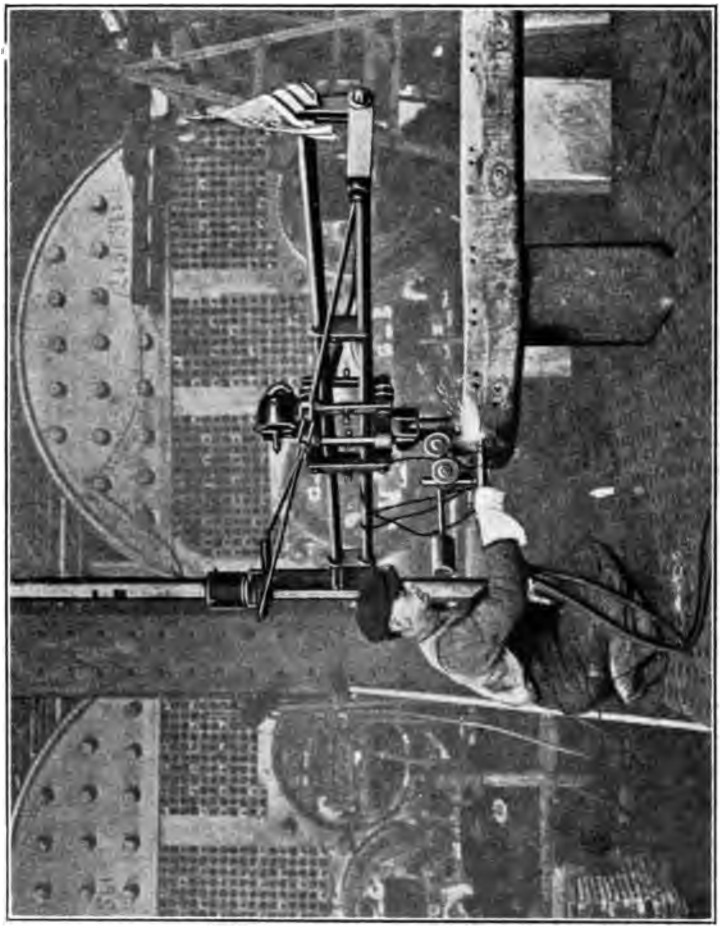


FIG. 72.—CUTTING ROUND THE FLANGE ON THE END OF A BOILER 8 FEET DIAMETER BY $1\frac{1}{4}$ INCHES THICK AUTOMATICALLY IN SIXTEEN MINUTES.

Manufacturers should use the oxy-acetylene cutting process much more than they do at the present time. They will find important advantages through operating the torches mechanically, when such a procedure is practicable. More notable among the benefits secured from mechanical control are increased production from the

cutters and greater uniformity of work. Experience is required to enable the hand operator of a cutter to produce uniform cuts. In shops, the use of mechanically operated cutters eliminates the personal equation and generally improves the quality of the work.

Figs. 72, 73, and 74 are remarkable and wonderful machines. You will note the ease with which the cutter is handled, also the clean-cut edge which it leaves, thereby saving machining.

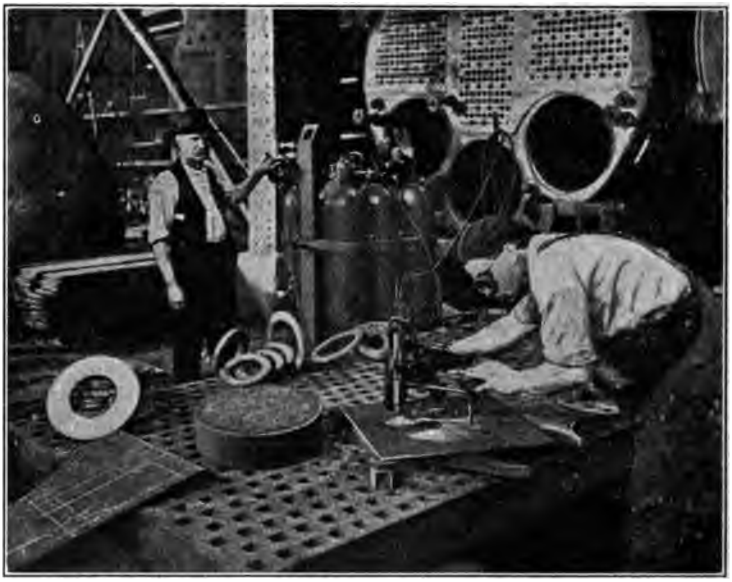


FIG. 73.—CIRCULAR CUTS IN STEEL PLATE 2¼ INCHES THICK, WITH THE RADIOGRAPH, AT A SPEED OF 6 LINEAL INCHES PER MINUTE.

Inside and outside diameters of these flue sheets for special heaters were cut with the Radiograph and the oxy-acetylene torch.

It is also the means of increasing production, as cutters are moved at the correct rate, which is predetermined by the feed mechanism.

Various mechanically operated equipments are designed for particular requirements. There are also standard designs of mechanical cutters and welding blowpipes, which are being used with great success. Provision can be made for the mechanical control of cutters adapted for use on parts of a variety of different shapes.

The three illustrations show that, in addition to making straight cuts on flat plates, it is quite feasible for cutters to follow irregular

outlines on flat plates, or to make cuts on cylindrically shaped pieces.

With many of these mechanical equipments, the cutters are guided in such a way that they follow the line upon which it is desired to make a cut without calling for special attention from the operator. As previously mentioned, the provision of power drive sets the pace of the cutter, so that it is fed to the work at a predetermined speed suitable for the thickness of the metal that is being cut. Figs. 72 and 73 show two mechanically worked cutters for cutting ragged edges for such pieces as boiler heads, which have a flange drawn up around the circumference. In Fig. 72 the cutter is shown trimming the flange off a boiler front which is made of steel plate 1½ inches thick. It will be apparent from the illustration that the cutter is supported by a head carried on a radial arm, on a machine which is so designed that the cutter head can be traversed in either direction on the radial arm, and this arm can be swung round the column of the machine. This combination of movement enables the cutter to be fed round the edge of cylindrically shaped pieces, as shown. The cutter head is furnished with the wheels, which engage both inside and outside of the work to provide for holding the point of the cutter in proper relation to the plate it is cutting. The cutter head is worked by the electric motor seen above the radial arm, which transmits power to the wheels on the head, so that they serve the double purpose of holding the cutter in the proper position, and feeding it over the work at the proper rate. The plate being 1½ inches thick, it cuts at a rate of 1 foot per minute, and leaves a sufficiently good finish, so that no subsequent machining operation is required. The Radiograph is a portable, motor-driven machine, combining carriage and driving mechanism with motor attached, oxy-acetylene or oxy-hydrogen cutting torch, and means for guiding the heating or cutting gases along straight or curved lines, at constant speed adjusted according to the thickness of the plate and size of the tip used.

In making motors for steam turbines, the New York Shipbuilding Corporation pour the molten steel into the mould, which is made so that the rotor casting stands on end, makes the casting longer, which acts as a riser, that applies pressure and assists in production of a solid casting. Obviously, it is necessary to cut off this surplus; and during the process of machining this steel casting is set up in a lathe. Supported in this way, it is an easy matter to rotate the casting at a suitable speed, so that a cutting blowpipe supported in the proper relation to the work will have the steel casting fed to the cutter, at the proper rate for making this cut.

The illustration below is the casting described herewith. You see that it is in the lathe, and cut through; the blowpipe is fixed over the casting.

This rotor casting is 9 inches thick by 16 feet 6 inches in circumference, and the cut was completed by the oxy-acetylene cutter in the remarkably short time of thirty-five and a half minutes. A good idea of the quality of the finished surface left by the cutter will be gathered from the illustration.

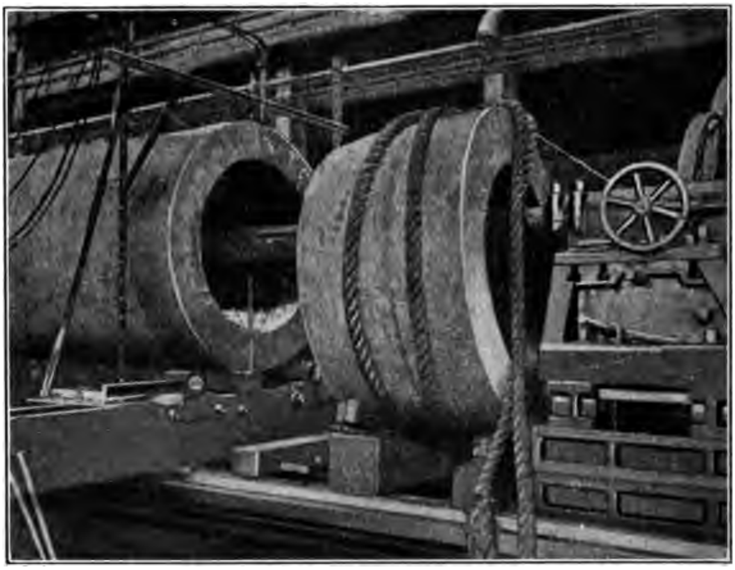


FIG. 74.—BODY OF STEAM TURBINE ROTOR OF CAST STEEL.

The end is being cut off by rotating it in the lathe to feed it to the flame of the cutting torch. It is 9 inches thick.

Users of cutting and welding blowpipes should make themselves familiar with the properties of both hydrogen and acetylene; but there are some who have not had occasion to investigate the properties of carbo-hydrogen. This gas contains from 85 to 88 per cent. hydrogen, and 15 to 12 per cent. of light hydrocarbons of the higher heating series. It is claimed that less oxygen is required for the combustion of this gas than for either acetylene or hydrogen; and the temperature of the carbo-hydrogen flame is approximately 4,800° F.

In referring to the properties of combustible gases which make

them suitable for use in cutting and welding, confusion frequently arises through a misconception of the relation which exists between the number of heat units per cubic foot of gas and the temperature which can be developed by the combustion of that gas. For the performance of the cutting and welding operations, the number of heat units per cubic foot of gas is a matter of minor importance in determining ability to give efficient service. It is the rapidity with which this heat is liberated to develop a high temperature which determines the suitability of the gas for use in the blowpipe.

The fact is well brought out by comparing the heat value of carbo-hydrogen with that of ordinary illuminating gas, the former having approximately 480 British thermal units of heat per cubic foot, while the latter has approximately 600 per foot. Despite this fact, illuminating gas is unsuitable for use in a blowpipe, because, although it has 25 per cent. more available heat per unit volume of gas, this heat is not liberated rapidly enough to generate a temperature suitable for the cutting of metals.

It is claimed by the Carbo-Hydrogen Company that this gas has readily cut armour plate up to 24 inches thickness, using standard apparatus, and that open-hearth steel pit castings 36 inches thick across have been cut in half by a special apparatus, using carbo-hydrogen as the combustible gas. For this work a number of oxygen cylinders were manifolded together and a preheating flame was used, which was provided by a blowpipe fitted with a $\frac{1}{4}$-inch gas pipe, taking oxygen from the manifold supply direct. Of course, this was an unusual operation, and the cut was not made by one continuous traverse of the cutter. In the case of the 24-inch armour plate this was made in one operation. The composition of the carbo-hydrogen gas is such that an accurate, clean cut is made, and the slag produced is almost pure oxide of iron, there being very little pure iron in it. This indicates that the cutting is accomplished by a complete process of oxidation, which is the ideal method, and not by melting the iron. Where metal is severed by melting it is almost inevitable that a ragged surface should be left in making a cut, so that it is necessary to employ some subsequent process of finishing before the work is ready for use.

In this chapter information has been presented concerning miscellaneous applications which have been made of mechanically operated cutting and welding blowpipes, and attention has been called to the benefits secured through the substitution of mechanical control of hand operations. Despite the increased production and higher quality of the workmanship secured through mechanical

10

operations, many manufacturers are continuing to use cutters moved over the work by hand. There is no denying that the latter method is capable of producing highly satisfactory results when the cutters are placed in the hands of skilled operators; but the average mechanic will frequently fail to produce good work until he has had some considerable amount of experience.

It is well worth while for the manufacturer who has use for the

FIG. 75.—FELLING A STACK WITH AN OXYGEN CUTTER.

oxy-acetylene torch to investigate carefully the requirements of his work, with the idea of determining whether it could not be handled by one of the standard cutting or welding machines.

If investigation shows that the work could not be handled on any of the available commercial equipments, the next step is to ascertain whether a special machine using standard cutters could not be developed at a reasonable expense. If so, development of such an equipment will usually prove a highly profitable investment, both from

the standpoint of direct earnings and also by making an improvement in the quality of workmanship where cutting or welding operations have to be performed.

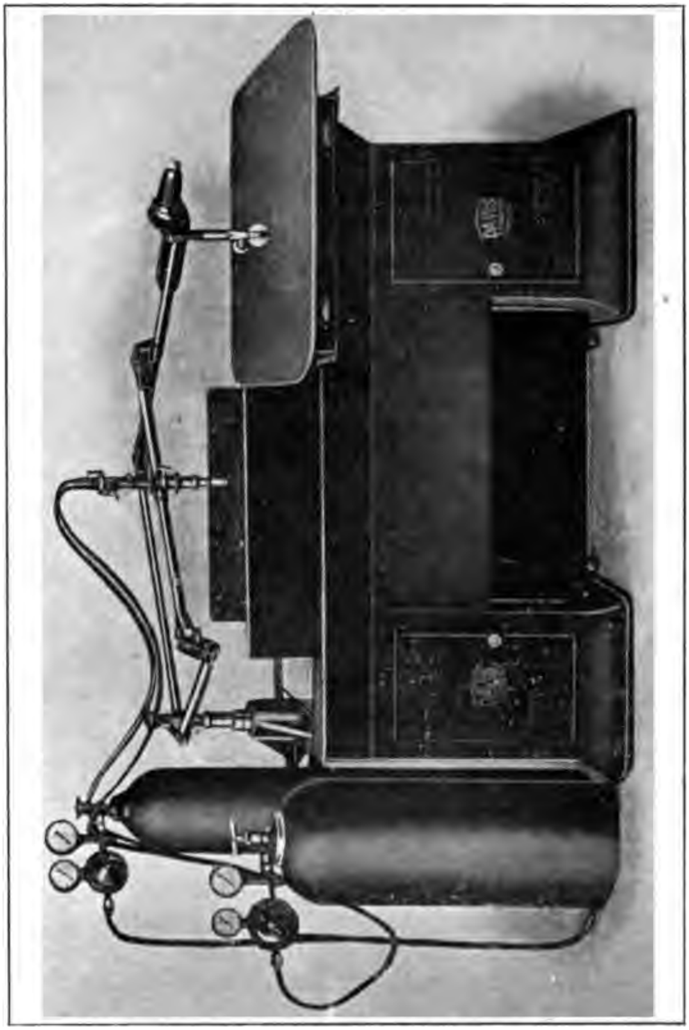


FIG. 76.—THE 1A OXYGRAPH.

Fig. 75 shows an unique application of the cutting blowpipe, the stack cut through at the bottom at an angle to set the fall.

Remarkable results, which have revolutionised many methods of

steel cutting, are being obtained with motor-driven machines. One such machine is sold under the name of "oxygraph." By following a drawing with a motor-driven tracer, steel to the thickness of several inches is cut out accurately in intricate forms. The motor is very small and compact and requires very little power. It can be driven either by battery or by wire attached to an electric-light fixture. Being motor-driven it moves with a uniform speed, and corners and curves are cut with great exactness.

It will cut steel plate from 1 to 15 inches or more in thickness, it cuts with a narrow smooth kerf, along straight lines, sharp angles, or curves, according to the drawing or pattern. The panta-

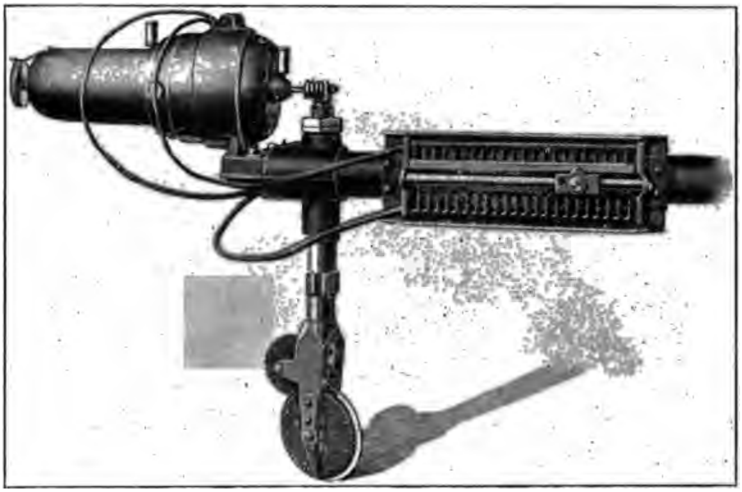


FIG. 77.—TRACER WHEEL, SWIVEL STANDARD, RHEOSTAT AND ELECTRIC MOTOR WITH SPEED CONTROLLER OF NO. 1A OXYGRAPH.

graph principle is employed with a motor-propelled tracing wheel, with which the lines of the drawing are followed and reproduced with the cutting torch. The only power required is for revolving the tracing wheel, and this is supplied by a small motor attached to the tracing head, which may be connected to the ordinary electric light or power circuit. The speed of the cutting varies from 2 to 18 inches per minute.

Machine torches of great power have been developed for oxy-acetylene and oxy-hydrogen cutting with the oxygraph that operate successfully on the heaviest work. The adjustment of the cutting flame is easily learned and skill in the operation of the machine

is soon acquired by inexperienced operators. An operator capable of running a drilling machine should be able to work the oxygraph efficiently after a few days' instruction.

The oxygraph has wide application and many uses in tool shops, manufacturing plants, locomotive works, shipyards, drop-forging concerns, and wherever tools, dies, forgings, and shapes are produced. The cutting action of the torch flame is smooth and rapid, and as any

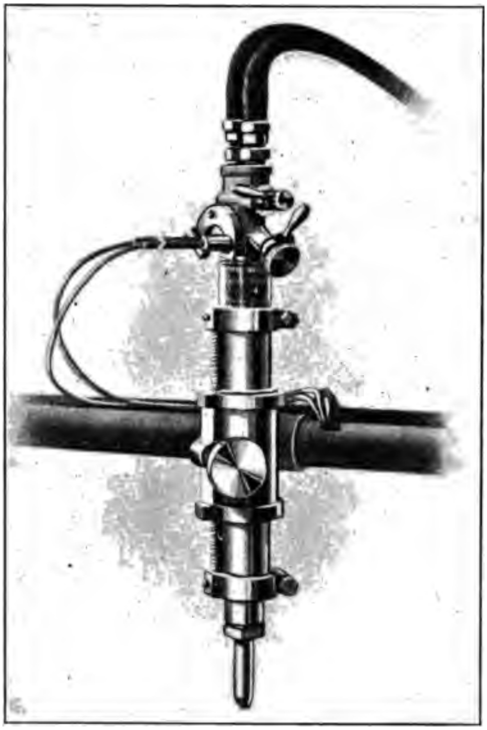


FIG. 78.—MACHINE CUTTING TORCH WITH MOTOR CONTROL SWITCH, AND RACK-AND-PINION VERTICAL ADJUSTMENT.

shape can be cut it is comparable to a metal bandsaw of great power, capable of cutting steel 15 inches thick at the rate of 4 or 5 inches per minute, following straight lines, curves, and angles, acute or obtuse. Thin sections are cut more rapidly, of course.

Punches, dies, stripper plates, and bolsters are cut in tool shops with the oxygraph with resultant saving of time and cost, reaching to 500 per cent., and even more, saving in some cases.

The usual practice in making a cutting or trimming die is to plane the block on the top and bottom, bevel the sides, lay out and drill holes to the line, cut out the walls between the drilled holes with a

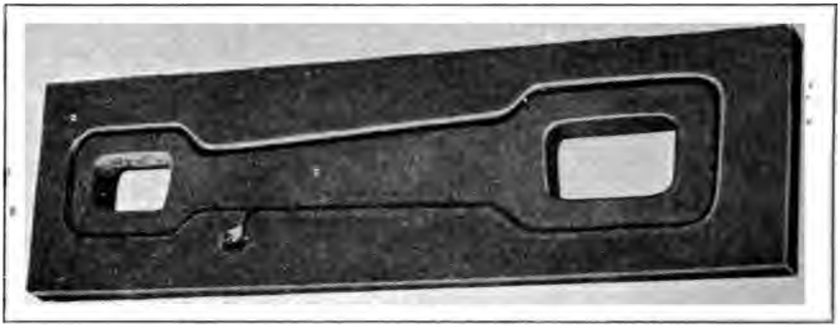


FIG. 79.—SMALL SOLID END CONNECTING-ROD AND BILLET FROM WHICH IT WAS CUT ON THE NO. 1A OXYGRAPH.

broach or drift, and finish with a hammer, chisel, and file, or by backing out on a shaper or slotter. Almost invariably a die made in this manner warps and twists in the process, and requires either re-

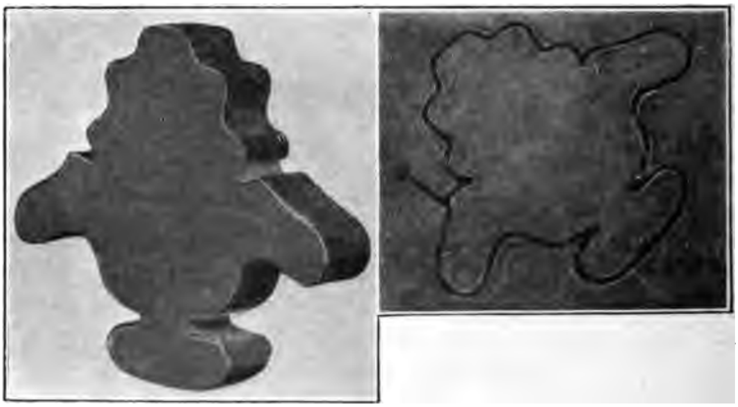


FIG. 80.—LEATHER-CUTTING PUNCH FOR SHOE MANUFACTURE AND TOOL STEEL PIECE FROM WHICH IT WAS CUT.

planing on the bottom or shimming up in the bolster. The removal of the mass of steel in the centre of the die relieves internal stress and lets the block warp out of shape. Not so when the rough die block is cut out with the oxygraph. All troubles of this sort are

eliminated and the danger of cracking in hardening is reduced to a minimum. The rough die block is preheated and cut before planing, using a paper drawing to guide the tracer wheel. When the opening has been cut, the die, still hot, is placed in an annealing box, covered, and left to cool. When cold it is planed and finished in the usual manner with the assurance that internal strains have been relieved. Finishing the die to precise dimensions and backing out for clearance is done in the usual manner.

Not only is the oxygraph useful for blocking out dies but it may be used also to cut the stripper plates and bolsters. The use of the No. 1A oxygraph in a tool shop outlined in the foregoing is one of the many that can be made in the manufacturing plant. It may be

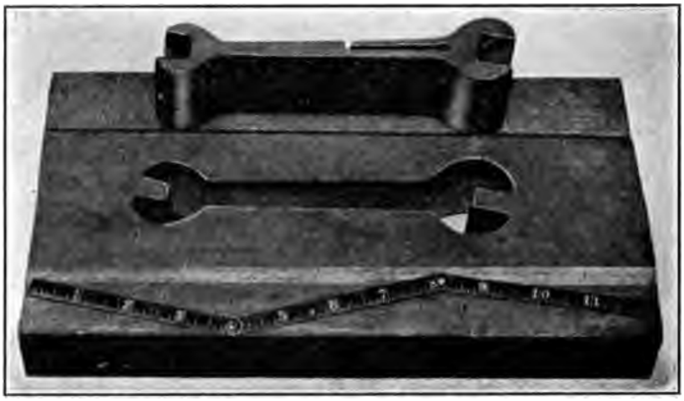


Fig. 81.—Drop Forged Wrench Trimming Die Roughed out on No. 1A Oxygraph and Ready to be "Backed Out."

used for cutting metal templates, cams, patterns, risers for fire escapes, and all shape cutting of any description which comes within the range and capacity of the machine.

The No. 2 oxygraph is designed for such work as cutting the side frames of mine locomotives, tadpole ends of rudder wings, crank-cheeks of marine engines, mast bands for ships, connecting-rods for locomotive and marine engines, locomotive valve motion links, eccentric rods, and hundreds of parts whose production by other means is slow and costly.

Figs. 79, 80, and 81 show a few samples of what is possible with these wonderful small machines; those shown are by the oxygraph.

The above and other illustrations following will serve to give

some range of work and the speed of performance. But no matter what the shape is, provided the metal is steel or wrought iron

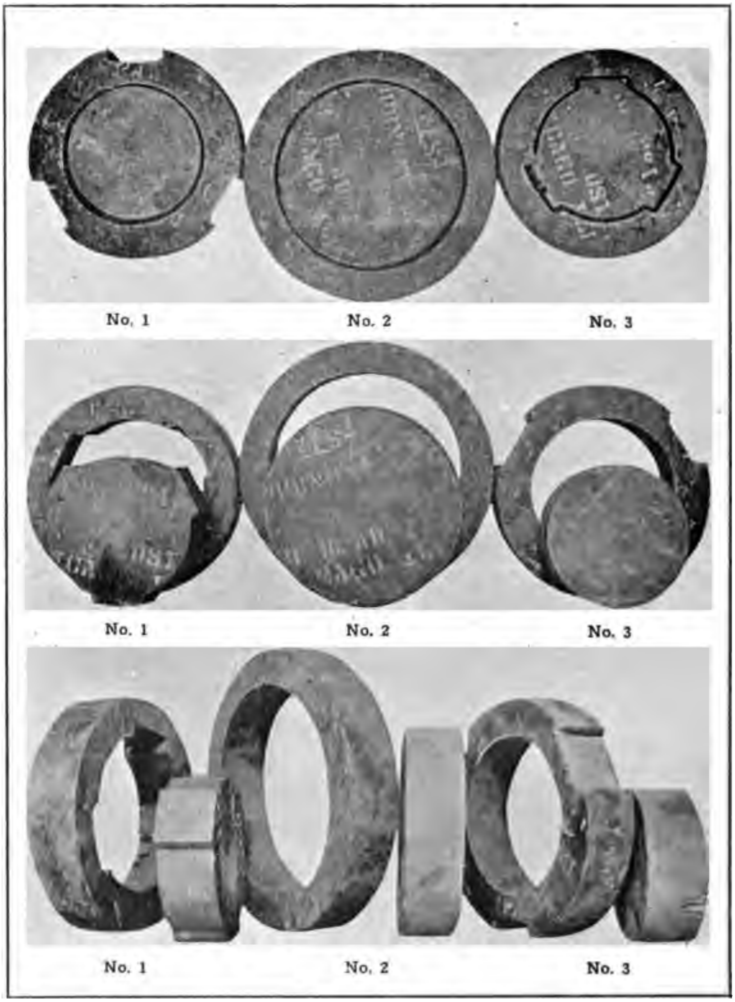


FIG. 82.—VIEWS OF THREE SETS OF DIES CUT FROM 110-POINT CARBON STEEL, $2\frac{1}{2}$ INCHES THICK, ON NO. 1 OXYGRAPH.

which may be forged to shape, it doubtless can be advantageously cut in the process of fabrication to reduce forging and machining cost. Forge shops use the oxygraph to increase the productive

capacity of their forging hammers and presses. For instance, a billet weighing many tons may be forged to a roughly rectangular shape, and from that be cut in two, three, or four crank-cheeks weighing, perhaps, 2 tons each. The resultant scrap, in some cases, is of a shape that can be utilised for smaller work by being reforged, hence saving not only time in forging and machining, but metal as well. Cutting may be started at the edge or within the edge of a piece, if conditions require it. The oxygraph torch flame quickly perforates, and thus the cost of drilling and handling is saved. The edges of the cut pieces are square and smooth and, in many cases, no machining is required for finish. If extreme accuracy is required, the cutting can be done so close to the line that machining is a light finishing operation only. These cutting machines are manufactured in America by Davis-Bournonville Company.

The following are the costs:

No.	*Time. Minutes.*	*Oxygen. Cubic Feet.*	*Acetylene. Cubic Feet.*	*Length of Cut. Inches.*	*Gas Cost at 1d. Cubic Foot. Pence.*
1	3·5	10·5	1·2	30	15
2	4·0	13·2	1·4	34	17
3	4·0	13·2	1·4	34	17
	11·5	36·9	4·0	98	49

CHAPTER XXIV

THERMIT WELDING

Thermit Process.—This process of welding metals is effected by pouring superheated thermit steel around the parts to be united. Thermit is a mixture of finely divided aluminium and oxide. This mixture is placed in a crucible, and the steel is produced by igniting the thermit in one spot by means of a special powder, which generates the intense heat necessary to start the chemical reaction. When the reaction is once started it continues throughout the whole mass, the oxygen of the iron being taken up by the aluminium (which has a strong affinity for it), producing aluminium oxide (or slag) and

Fig. 83.—The Above is a Thermit Weld, in which New Teeth have been Welded in.

superheated thermit steel. Ordinarily, the reaction requires from thirty-five seconds to one minute, depending upon the amount of thermit used. As soon as it ceases, the steel sinks to the bottom of the crucible, and is tapped into a mould surrounding the parts to be welded. As the temperature of the steel is about 5,400° F. it fuses and amalgamates with the broken sections, thus forming a homogeneous weld.

It is necessary to preheat the sections to be welded before pouring to prevent the chilling of the steel. The principal steps of the operation are: to clean the sections to be welded; to remove enough metal at the fracture to provide for a free flow of thermit steel; to align the broken members and surround them with a mould to retain

the steel; to preheat by a torch or other suitable heater to prevent chilling the steel; to ignite the thermit and tap the molten steel into the mould.

This process is specially applicable to the welding of large sections. It has been extensively used for welding locomotive frames, broken motor castings, rudders and sternposts of ships, crankshafts, spokes of driving wheels, connecting-rods, and heavy repair work in general. One great advantage of the thermit process is that broken parts can usually be welded in place. For example, locomotive frames are welded by simply removing parts that would interfere with the application of a suitable mould. Thermit is also used for pipe welding and in foundry practice to prevent the "piping" of ingots.

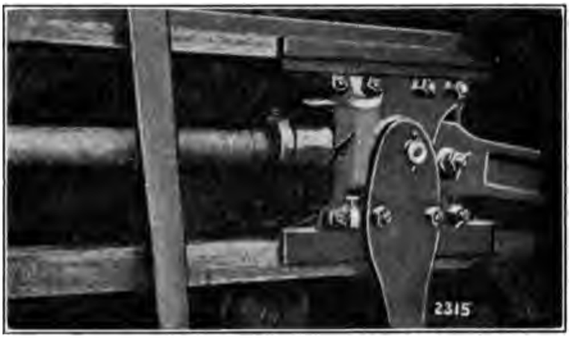


FIG. 84.—THERMIT-WELDED CROSSHEAD.

Preparation.—The first step in the operation of thermit welding is to clean the fractured parts and cut away enough metal to ensure an unobstructed flow of the molten thermit. The oxy-acetylene cutting blowpipe is very efficient for this operation. The amount that should be cut away depends upon the size of the work. Assuming that a locomotive frame is to be welded, the space should be about $\frac{3}{4}$ inch wide for a small frame, and 1 inch wide for a large frame. The frame sections are then jacked apart about $\frac{3}{4}$ inch to allow for contraction of the weld when cooling. Trammel marks are scribed on each side of the fracture to show the normal length. If the weld is to be made on one member of a double-bar frame, the other parallel member should be heated with a blowpipe to equalise the expansion in both sections and prevent unequal strains.

Fig. 84 shows a Thermit-Welded Crosshead, which was broken

through the middle before welding took place. The two pieces of the crosshead, before welding, are bevelled on each edge of the fracture, so as to give a further area of thermit, thereby getting greater strength in the weld. The bevelling was done with an oxy-acetylene cutter, using acetylene and oxygen.

Mould for Thermit Welding.—The mould surrounding the fractured part should be so arranged that the molten thermit will run through the gate to the lowest part of the mould and rise through and around the parts to be welded. The thermit steel is poured through the gate and forms a riser which rises into a space after passing round and between the ends of the fractured crosshead. The thickest part is directly over the fracture, and the band overlaps the edges of the fracture by at least one inch. An opening is also made for preheating the ends to be welded.

Patterns for the riser, pourings, and heating gates can be made of wood. The riser should be quite large enough, because the steel that first enters the mould is chilled somewhat by coming in contact with the metal even when preheated. This chilling effect is overcome by using enough thermit steel to force the chilled portion into the riser and replacing it by metal which has practically the full temperature received during reaction. When the mould and the box are filled and tamped, the wooden runner and riser patterns are withdrawn. The mould is then ready for the preheating and the drying operation, which causes the wax matrix to melt and run out. The mould must be made of some refractory material, owing to the intense heat.

Thermit welding was first introduced in 1903 and was adopted on marine work, which has had a great many successful welds of this nature. It is being used largely by railway and tramway companies. One can, nearly always, see the process being worked in the streets on the tramway lines.

There are many technical schools in every large city, where instruction and practice are given in thermit welding, as well as other welding processes.

Thermit Required for Welding.—The quantity of thermit required for making a weld can be determined from the cubic content of the weld. Calculate the contents of the weld and its reinforcement in cubic inches, double this amount to allow for filling the gate and riser, and multiply by 0·56 to get the number of pounds of thermit required. When wax is used for filling, the weight of the thermit can be determined as follows: Weigh the wax supply before and after filling the fracture. The difference in weight (in pounds) of

the quantity used multiplied by 22 will give the weight of thermit in pounds.

When a quantity of more than 10 pounds of thermit is to be used, add 10 per cent. of steel punchings (not over $\frac{1}{2}$ inch diameter), or steel scrap, free from grease, to the thermit powder. If the thermit exceeds 50 pounds, 15 per cent. of small mild steel rivets may be mixed with it. One per cent. by weight of pure manganese and 1 per cent. of nickel thermit should be added to increase the strength of the thermit steel.

Preheating—Making a Weld.—The ends to be welded should be red-hot at the moment the thermit steel is tapped into the mould. This preheating is done preferably by a gasolene compressed air burner. As previously mentioned, it melts the wax matrix used for filling the fractures to form the pattern for the reinforcing band. When the ends have been heated red, quickly remove the burner and plug the preheating hole with a dry sand core, backing it up with a few shovelfuls of sand, well packed. The end of the cone-shaped crucible should be directly over the pouring gate and not more than 4 inches above it. To start reaction, place $\frac{1}{2}$ teaspoonful of ignition powder on the top of the thermit and ignite with a storm-match. It is important that sufficient time be allowed for the completion of the thermit reaction and for the fusion of the steel punchings which have been mixed with the thermit.

With charges containing from 30 to 40 pounds of thermit, the crucible should not be tapped in less than thirty-five seconds; with charges containing 50 to 75 pounds, forty seconds; 75 to 100 pounds, fifty seconds to one minute. When welding a broken frame, as shown previously, the screw jack used for forcing apart should be turned back somewhat to relieve the pressure gradually as the weld cools. After pouring the mould should remain in place as long as possible (preferably ten to twelve hours) to anneal the steel in the weld; and, in any case, it should not be disturbed at least two hours after pouring. When welding a broken spoke in a driving wheel or a similar part, it is necessary to preheat the adjacent spokes in order to prevent undue strains through expansion and contraction. If a section of a spoke is broken out, it can be cast in, but if the space is over 6 inches long it is better to insert a piece of steel and make a weld at each end. Owing to the high temperature (5,400° F.), and the violent ebullition of thermit during reaction, the crucible must be relined with a very refractory material. The crucibles used for this purpose have sheet-iron shell and are lined with magnesia.

Filling Shrinkage Holes and Surface Flaws.—The filling of surface flaws in castings and forgings usually requires from 2 to 10 pounds of thermit.

To make a weld of this kind, place an open mould around the part to be filled large enough to overlap it about ½ inch; clean the hole thoroughly and heat to red-heat by means of a strong blow-burner. Use 18 ounces of thermit for each cubic inch of space,

FIG. 85.—THERMIT-WELDED ROCK CRUSHER.

but not less than 2 pounds for any one weld. Place a small amount of thermit in the crucible, which, in this case, is of a small size for hand use. Ignite the thermit with the ignition powder, and as soon as it begins to turn add the remainder, feeding it fast enough to keep the combustion going. When the reaction is completed quickly pour the slag (which is about three-fourths of the liquid) into dry sand. Then pour the steel into the open mould and sprinkle

loose thermit on the top to prolong the reaction, as the casting, even when preheated, will have a chilling effect on the steel.

Composition of Thermit Steel.—An average analysis of thermit steel is as follows: Carbon, 0·05 to 0·10; manganese, 0·08 to 0·10; silicon, 0·04 to 0·05; aluminium, 0·07 to 0·18 per cent. The tensile strength is about 65,000 pounds per square inch.

Fig. 85 is a remarkable weld of a rock crusher for the Casparis Stone Company. The eccentric bearing broke off, leaving a fractured surface extending longitudinally through the bearing, measuring 6 feet 2 inches long and an average of about 7 inches thick. A mechanical repair was first attempted on the new brake, which, however, failed only after a few days' service. Resort was then made to the thermit process, and the casting was shipped to the thermit factory. The broken sections were lined up, a gap of about 3 inches between the sections was cut out with the oxy-acetylene flame, 90 pounds of wax applied in the welding gap, and a mould box built round the fracture. Six preheating gates were made in the mould. The preheating was begun at 4 a.m. on the day of the pour; 1½ hours of preheating were required to burn all the wax out of the mould. The preheating was kept up for about twelve hours until 3.45 p.m., the time the reaction started. The weld is illustrated on p. 158.

Particular interest attaches to this repair because an extra large crucible, having a capacity of 2,000 pounds of thermit, and of somewhat different design from the standard crucible, was used experimentally. The crucible was filled almost to its 2,000 pounds capacity, 1,750 pounds of railroad thermit being used. In spite of the enormous amount of thermit formed in one crucible, the reaction and pour were accomplished with entire success. The crucible rested steadily and motionless on its four supports throughout the reaction. Sixty seconds were allowed for the reaction to take place, after which the crucible was tapped in the usual manner, in the case of large welds by means of a long iron rod. From the moment of tapping it took two and three-quarter minutes for the contents to run out, as compared with the one minute generally required in the case of number 10 crucible. The illustration is self-explanatory. It shows the arrangement of the gates and riser, and indicates the excess of metal present after the mould box was finally removed.

CHAPTER XXV

PROPERTIES OF PRINCIPAL NON-FERROUS METALS

SCATTERED throughout the pages of technical literature are various references to non-ferrous metals and alloys, the importance of which is apt to be lost sight of because they become inaccessible after a short time. It is therefore desirable that such information should be carefully sifted and what is useful in it collated and presented in a handy form. Such is the purport of the present chapter.

The science of metallurgy has developed wonderfully within the last few years, especially with regard to the non-ferrous metals. Manufacturers are awakening to the fact that many of the disturbing influences which mar their best efforts are due to prevalent misconceptions respecting the combined chemical compositions and the physical structures of the materials, and that henceforward science and practice must go hand in hand if true progress is to be attained.

An ordinary chemical analysis, supplemented by the usual physical tests, was, at one time, considered to give the total history of an alloy. Things have changed, however, and it is now recognised that metals and compounds may be incorporated in an alloy under conditions which would so change the arrangements of the constituents as to render it difficult, if not impossible, to determine the original state of combination or the ultimate condition of the product. There has been no lack of fanciful theories in regard to the segregation, crystallisation, and fatigue of metals, some of them based on insufficient data derived from purely physical and chemical tests.

A new branch of metallurgical study has recently come into prominence under the name of "metallography"—that is, the microscopical examination of the structure of metals, which has already been the means of revealing the causes of many peculiarities of metals and their alloys and confirming other theories concerning them which used to be looked upon as parabolic. One of the most important properties or changes which occur in alloys is that of liquidation, which was only proved by metallographic examination.

When a solution fluid at ordinary temperature is allowed to cool

below its congealing-point, the process frequently takes place in such a manner that, as cooling progresses, certain constituents of the solution congeal first, whilst the solution still remaining liquid undergoes constant changes in composition until a certain point is reached, after which this solution also congeals. The solution congealing last is called the eutectic (most fluid) solution. On examination of the latter, it will be found that during cooling a disintegration of the constituents previously dissolved in one and another has taken place, and that the solution now forms only an intimate mixture of these constituents.

Many alloys show a similar behaviour when cooling. If, for instance, a melted zinc-copper alloy containing more than 72 per cent. of zinc be allowed to cool, zinc crystals are first separated, while an alloy poorer in zinc still remains liquid. This separation of zinc is continued until the content of the zinc has been reduced to 72 per cent., which takes place when the temperature has fallen to 1,404° F. This is the eutectic point: a eutectic alloy which no longer separates any constituents but solidifies throughout at that temperature consists, therefore, of 72 parts of zinc and 28 parts of copper. In congealing it disintegrates, however, to an intimate mixture of its constituents which, on reheating, first dissolve again in one another, and with an increase of temperature gradually dissolve the previously separated zinc. If, on the other hand, the alloy contains less than 72 per cent. of zinc and more than 28 per cent. of copper, copper is, in congealing, first separated till, at 1,404° F., the composition of the eutectic alloy has again been reached and then also congeals.

Specific Gravity.—The specific gravity or density of alloys corresponds only in a few cases with that which would result by calculation from the specific gravities of the constituents. The specific gravity should be calculated from the volumes and not from the weights. Dr. Ure gives the correct rule as follows: Multiply the sum of the weight into the products of the two specific gravity numbers for a numerator and multiply each specific gravity number into the weight of the other body, and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the computed mean specific gravity of the alloy. With regard to the influences exerted upon the strength of metal by alloying, the following general law may be laid down. By the absorption of a foreign body the strength of the metal is increased. It grows with the content of the foreign body until the latter has reached a certain proportion, which varies in individual cases.

When this limit has been passed, the strength again decreases, frequently with great rapidity, provided that the body itself does not possess greater strength than the metal. By the addition of a third metal to an alloy consisting of two metals, it is sometimes possible to bring about an additional increase in strength.

Limit of Elasticity.—In alloying a metal the limit of elasticity increases steadily with the breaking strength, limit of elasticity, and breaking weight moving more closely together. The limit of elasticity usually increases still further when, with the increase of the foreign body added, the highest degree of strength has already been attained, and a decrease in strength reappears. Limit of elasticity and strength sometimes finally converge.

MIXTURES OF ALLOYS.

	Copper.	*Tin.*	*Zinc.*	
Bell-metal	78	22	—	Standard bell-metal
Gun-metal	90	10	—	Ordnance castings
Gun-metal	88	10	—	Steam chest pumps
Gun-metal	86	14	—	Hard bearing metal
Naval brass	62	1	37	Stanchions, tube plates
Sheet brass..	70	—	30	For sheet tubes
Ordinary brass	66⅔	—	33⅓	General use
Manganese bronze ..	56	0·9	41	
Gun-metal ord.	88	8	2	General use
Yellow brass	85	3	15	General plumbing work
			Iron.	
Phosphor-bronze	89·5	10	0·5	Heavy bearings

MELTING AND BOILING POINTS OF METALS.

	Melting-Points. Degrees C.	*Boiling-Points. Degrees C.*
Aluminium	658·7	1,800
Copper	1,803	2,310
Iron	1,520	2,450
Tin	231·9	2,270
Zinc	419·4	905·7
Gun-metal	995	1,825
Red brass	970	1,780
Low-grade brass	980	1,795
Bronze with zinc	980	1,795
Cast yellow brass	895	1,645
Naval brass	855	1,520
Manganese bronze	870	1,600

The purest metals possess the greatest flexibility. By alloying this property is diminished, and sometimes almost reduced to nothing. The melting temperature of metals is frequently lowered by alloying. Therefore it is essential that, when welding takes place upon non-ferrous metals, precautions must be taken not to add impure metals from the welding-rod into the welded portion. Also it is important that the metal article being welded and the welding-rod shall be one and the same material, plus ingredients to replace the element that is volatilised during welding.

CHAPTER XXVI

DELTA METALS

THE alloys known under the name of "delta metals" are a series of high-class engineering alloys, of which the first was placed on the market in 1885 by the eminent metallurgist, the late Alexander Dick. These metals have been greatly developed and comprise a whole group of different alloys. Hence there are naturally always welding repairs in these metals to be done. A description of their properties will enable the student to distinguish them from other metals and alloys, so that the treatment may be administered as required.

It is obviously impossible to combine in one single alloy all the physical and chemical properties suited to a great variety of purposes. The different standard alloys vary in composition according to the purposes for which they are more particularly adapted.

Some alloys possess in every degree the properties of malleability, strength, and resistance to corrosion; others are superior bearing metals. Some have particular qualifications for electrical purposes; others for high-speed machining for brass-founder's work. One is called silver bronze, possessing a silver-white colour.

Metal No. 1: Strongest malleable bronze for high-tensile forgings, castings, and rods.

Metal No. 2: Silver bronze (improved nickel silver) rods, forgings, and castings.

Metal No. 3: Specially adapted for solid drawn tubes.

Metal No. 4: (Various grades) malleable bronze, strong as steel, tough as wrought iron, highest resistance to corrosion, for castings, forgings, stampings, rods, sheet, wire, etc.

Metal No. 5: Antifriction bronze for bearing castings.

Metal No. 6: Improved gun-metal for castings of every description.

Metal No. 7: Bronze to resist high temperature, castings, forgings, stampings, rods, etc.

Metals Nos. 8, 9, 9*a*: Various grades of white antifriction metals.

Of the various alloys, the most used is No. 4. Its great strength,

equalling that of steel, its elongation, its toughness, its malleability, and its property of resisting in a marked degree the corrosive action of sea and mine water, chemicals, gases, etc., render this particular brand the most useful for all classes of work in which durability, strength, and reliability are the qualities chiefly to be taken into consideration. It should be borne in mind that when objects made from different metals or alloys are, while in metallic contact with each other, immersed in sea water, brine, or any other exciting fluid, galvanic action will be set up, which will bring about deterioration or decomposition of the metals. The rapidity with which this deterioration takes place, and also the question of which of the metals is chiefly attacked, depends upon the relative position of the different metals in the electric scale. Metals hardly suffer at all when in contact with those which are electro-negative to them; but when in contact with a metal which is electro-positive towards them they are rapidly destroyed. For this reason delta metal should never be placed in metallic contact with copper or gun-metal when immersed in sea water, or used in running machinery or other plant which is exposed to the action of corrosive fluids.

From this it is clear that operators should take care in the welding of delta-metal articles. A welding-rod must be used of the same constituents as the article being welded, plus the deoxidising substance. The results of tests from this metal have shown it to have a tensile strength of 24 tons per square inch, elongation from 30 to 40 per cent., and limit of elasticity 19·02 tons per square inch. When reheated to 550° C. (a dull red colour) it becomes soft, and is then one of the most malleable copper alloys in existence, as it is in a semiplastic state, in which it can be worked as easily as wrought iron, and can be stamped, forged, and pressed to any extent required. As these operations add 50 per cent. strength to the metal, without impairing any of its other valuable qualities, it is obvious that, for the majority of uses, the wrought material is to be preferred, the more so as it is free from defects which are sometimes found in castings, such as blowholes, etc.

Forged bars of this alloy show, as a result of four tests, a tensile breaking strain of 34·4 tons per square inch, with an elongation of 26·25 per cent. Its great strength is but little affected by increase of temperature. This quality adds considerably to its value for engineering purposes, such as engine fittings exposed to hot steam. The result of the test at a temperature of 506° F. was that it lost only about 17½ per cent., while at 500° F. brass lost 38 per cent., phosphor-bronze about 31 per cent., and gun-metal 33 per cent. Delta

metal can be roughly described as a copper-zinc alloy, chemically combined with definite proportions of iron and other elements. The secret lies, not only in the use of virgin metals in the exact proportions, but still more in the proper methods of combining these, and eliminating during the manufacturing processes certain other elements after these have produced the desired effect.

The foregoing description is one which sets out the properties of a metal very largely used in many workshops. The author has not seen them detailed before; but he has had considerable experience in the welding of it, and articles made of it are now coming into various workshops or welding depots for repairs.

Welding-Rods.

Welding-rods for use with delta-metal articles should contain the same pure metal, and also a trace of phosphorus and aluminium. These are added to the metal to prevent oxidation. The welding-rod should be manufactured from pure metal, and the constituents or ingredients uniformly distributed through the mass. They should be made in sizes from $\frac{1}{8}$ to $\frac{1}{2}$ inch diameter and 24 inches long. They are usually drawn down into wire of various thicknesses and stocked by the manufacturers. They should also be made in various grades to suit the articles to be welded.

Preparation of Articles.

The welding of delta metal is easy of application, as the metal is very pure. The area to be welded must be bevelled in the usual course. If it is not over $\frac{3}{8}$ inch thick it is only necessary to bevel one side, but if over $\frac{3}{8}$ inch thick it is necessary to bevel both sides. Afterwards the weld has to be thoroughly cleaned. This is very important, because the molten metal will not adhere to a greasy surface.

Preheating.—The laws of expansion and contraction have necessarily to be considered in welding this metal. Therefore, it is desirable always to preheat the articles, and, after welding sharply, they should be returned to an annealing furnace to heat up and allowed to cool slowly until quite cold. Apart from the question of expansion of the metal, preheating saves a good quantity of gases in welding.

Blowpipe Power.—The power of the blowpipe is, generally speaking, the same as for copper, or a size larger than that used for iron or steel. The regulation of the flame is very important. This must

be done with great accuracy, and there must be no excess of acetylene or oxygen. The former would carbonise the weld, the latter would oxidise it. The oxygen pressure must not at all be increased over that stated by the makers. The flame should be regulated till a clear white jet or cone is perceived and kept at this until the blowpipe gets somewhat heated and the flame begins to get less, when a little more acetylene should be turned on to make the even cone. In no case should excess oxygen be turned on.

Method of Welding.—The preheated and bevelled article should be on the welding table, the blowpipe regulated, and the welding-rod in the left hand. Approach the welding line at about $\frac{1}{2}$ inch from the edge, keeping the white top of the flame $\frac{3}{16}$ inch from the metal. As the melting starts, the blowpipe should be passed over to the edge, and this melted. At this period the welding-rod should be nearly at the welding-point. As soon as the edge is melted, put a little from the welding-rod into the molten mass to fill up the bevel, and continue the movement of the blowpipe along the line of welding in a gyratory movement, advancing at the same time with the necessary addition of the welding-rod to fill up the spaces until there is enough metal added to fill up the bevel. The welding must be continuous when once started, and one must not go over the weld twice without adding additional welding-rod. The flux must be used along with the welding-rod, and dipped while hot into the flux jar. No more must be used than is necessary—just sufficient to clean the metal and prevent oxidation. When the weld has been completed, the welded article should be put back into the annealing furnace and heated to 550° C., then, when cold, the weld may be hammered.

Failures.—These only occur through lack of metallurgical knowledge: adding a rod of inferior quality; bad penetration; allowing the oxide to form internally in the metal, forming blowholes; being too long on the weld, and causing the metal to become too liquid, burnt, and oxidised; or melting the metal to its boiling-point instead of its melting-point.

All these defects are easily overcome. They require a little practice and careful study of the metallurgical and technical points. With this knowledge failure is impossible.

CHAPTER XXVII

ALUMINIUM

ALUMINIUM has a silvery-white appearance, and is capable of taking a very high polish. It is one of the soft metals, its hardness being only about 2·5. Its most valuable property is its lightness, the specific gravity being 2·56, varying slightly with the impurities present. Rolling, hammering, and stamping increase its specific gravity somewhat, that of worked metal being as high as 2·7. The tensile strength of aluminium castings is about 6 or 7 tons per square inch in section, although wire may reach 15 to 30 tons, depending on its fineness.

The elastic limit is about 3 to 4 tons in the case of castings, and may be as high as 15 tons for wire. The metal flows readily under pressure, and is therefore both malleable and ductile. It can be rolled into very thin sheets or drawn into fine wire. Aluminium melts readily, its melting-point being 658° C., and its boiling-point is estimated at 1,800° C., being non-volatile in ordinary circumstances. It has a very specific heat, about 0·308, which remains constant up to about 800° C. Its latent heat of fusion is given as 100. It is a good conductor of electricity, the conducting power of pure aluminium (silver taken as 100) being about 56; but this should be modified by the presence of impurities, and by the condition of the metal, whether annealed or not, owing to its lightness. For equal conductiveness the weight of the aluminium is about 48·5 per cent. that of copper. It is used largely in the manufacture of alloys and for many purposes, and is in big demand for motor-car castings, whilst its further use has been extended by the advent of the aeroplane. Owing to its low tensile strength, its usefulness has been curtailed for many engineering purposes. Hence many aluminium alloys have been brought out in the effort to combine strength with lightness.

The lightness, low cost, and ease of working peculiar to sheet aluminium have combined to make it one of the most popular metals for the manufacture of various articles from the sheet form. The metal can be obtained in grades from dead soft to hard rolled. A square

foot of 14 S.W.G. sheet aluminium weighs 1·11 pounds, the same size copper weighs 3·70, and brass 3·56 pounds. The difference in prices for the same sizes is as follows:

One square foot of sheet aluminium	costs	1s. $2\frac{1}{2}$d.
,, ,, ,, copper	,,	3s.
,, ,, ,, brass	,,	2s. 6d.

Hence aluminium is much less than half the cost of other non-ferrous metals; in sheet form it is undoubtedly (with the exception of iron) the cheapest material on the market. For this reason sheet aluminium has come into extended use for such work as motor body and railway coach construction, for ceilings and panels, and many other purposes. The welding of this sheet aluminium is spreading rapidly. Operators should devote much time to its study from a metallurgical point of view, so that when they come to weld it they may understand what takes place when the heat of the flame is used on the sheet and it becomes molten.

Aluminium is without doubt the most difficult to weld of all metals. This is largely due to the difference in the fusibility of the aluminium oxide and aluminium metal. When two separate pieces of aluminium are welded together at their edges, by means of the welding flame, the melted parts do not flow properly together, as is the case with iron, where the melting-point of the oxide is lower than that of the metal. At high temperatures aluminium has great affinity for oxygen. The molten parts become covered, under the influence of the welding flame, with a fine coating of oxide, which has great power of resistance to the flame, and, on cooling, the parts remain unjoined. Therefore, if aluminium parts are to be welded together properly, this skin of oxide must in some way be destroyed. This can be done to some extent mechanically. The destruction of the covering of the oxide can be brought about by moving or puddling the molten metal of the weld by means of the aluminium wire used as a feeding-rod to let the separate drops, already formed, flow to one another. With this method, however, there is a danger that the weld will be a failure, not a homogeneous one. Almost certainly some part or other of the oxide will remain in the weld, which would probably make it defective. There are also many points to watch carefully in the welding of aluminium. It is imperative that it be supported on the underside of the weld. Otherwise, as soon as the melting takes place the molten metal would fall through, leaving a hole in the weld, which the student would find it difficult to fill up without causing further holes and burning the aluminium, causing

even further oxidation. Mechanical puddling should not be practised, because it is only a makeshift, which is seldom successful. Proper welding—that is, a homogeneous joint—can only be done by very careful study and practice. An important point is the use of a good flux, which will cause the oxide to melt or break down to the same temperature and at the same time as the metal itself.

The difficulty will be seen when it is explained that the melting-point of metallic aluminium is 650° C., whilst the melting-point of aluminium oxide is 1,800° C. To produce a flux that will dissolve the oxide at the low melting-point of the metal, and at the same time protect the hot metal from contact with the air, is no easy problem to the chemist and metallurgist. It is only recently that such fluxes have become obtainable. These vary considerably in their elements and compositions. There are several at present being marketed. Each one pleads it is the best; some are good, but others are no use whatever. If a good flux is obtained, there should be no reason (after constant practice) why operators should not make very satisfactory welds in aluminium. Light hammering of the weld and reheating to a temperature of about 450° C. are beneficial. Aluminium welding is now quite an important branch of the oxy-acetylene welding industry, and is employed more particularly in connection with brewing, where aluminium is largely superseding enamelled ware. Fluxes should always be removed by washing off as the welding job is complete.

It is very important to choose with care a correct blowpipe for the welding of aluminium sheeting. This must be a very light one, much lighter than for the same thickness of iron or steel: just half the power would be plenty. One must also be very careful to watch the oxygen pressure. This must be less than that specified by the makers, which is based on iron and steel. In all cases of welding pure aluminium it is imperative that the edges to be welded shall be absolutely clean, and the welding-rod of the purest metal obtainable, so as not to get impurities into the weld, which would cause it to be defective.

Aluminium being of low melting-point, the operator requires great patience and skill when welding, and must avoid burning the metal, or getting much above its melting-point, as the heat spreads rapidly, especially on light work.

If the metal melts too much on each side of the weld and makes too large a molten bath, the result is a rough and probably defective weld. Therefore, neither the blowpipe nor the flame must be

large, and the oxygen pressure must be just sufficient to keep in the flame, which must have the smallest jet possible.

The welding-rod for aluminium welding is usually made from pure aluminium drawn wire of diameters for the various thicknesses to be welded. These rods are usually kept in stock by various factors of acetylene equipment.

It is imperative that the rods be pure, and free from even a trace of copper. Copper is very detrimental to welds and causes (in moisture or water) corrosion. In welding pure aluminium parts it is not always necessary to preheat, because in many cases the

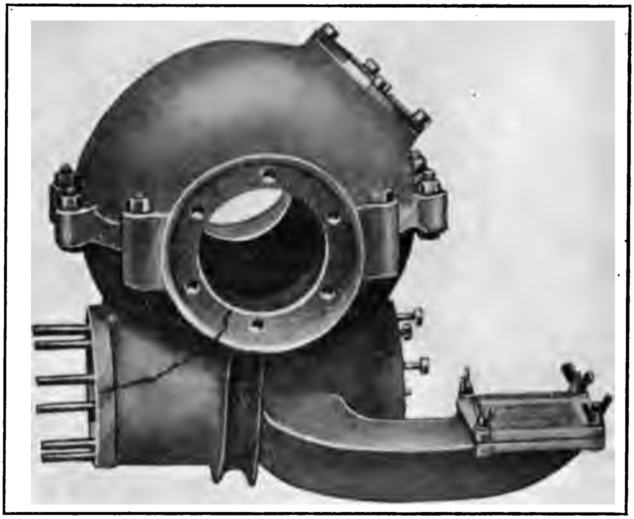


FIG. 86.—FRACTURED ALUMINIUM GEAR CASE.

aluminium article is able to stand the welding without preheating; but hammering and annealing afterwards increase the strength of the weld greatly. If flux has been used, the article should be brushed in running water if possible, because the flux has a corroding effect on the metal.

The above illustration shows a motor aluminium crank case which was welded successfully and afterwards annealed. A neat job was made and in no way distorted.

In dealing with alloys the most important properties which are desired are strength and durability combined with ductility. Tests have been applied to commercial specimens of alloys upon the market.

Alloys which are lighter than aluminium itself generally contain magnesium, which reduces its tensile strength, and renders it brittle and less permanent than aluminium itself. An alloy containing approximately 76 per cent. of aluminium, 21 per cent. of zinc, 3 per cent. of copper, has an ultimate strength of 12 tons per square inch. This is a mixture from which motor crank cases are frequently made.

Copper alone does not result in any great gain in beneficial properties, as is seen by the fact that an alloy approximately 95 per cent. aluminium and 5 per cent. copper only reached a maximum ultimate stress of 8 tons per square inch. With the exception of duralumin, none of the commercial alloys investigated showed any remarkable excellence, or, indeed, bore out the claims of the makers. Independent investigation in the laboratory with alloys of definite composition afforded interesting results which were exhaustively tabulated according to the method of mechanical and heat treatment. The result of annealing after treatment was invariably to lower the ultimate strength, while rolling had the opposite effect.

Sand cast alloy containing 15 per cent. of zinc had an ultimate strength of 11·19 tons per square inch, but a rolled bar reached in one case to 17 tons, wire being 19 tons per square inch, even after annealing at 400° C. An alloy containing 20 per cent. zinc showed higher tensile strength all round, sand cast 17 tons per square inch, 1¼ inch diameter rolled bar 22½ tons per square inch. Copper alone in small quantities does not cause any appreciable improvement, but it can be advantageously used in conjunction with zinc. Experiments with aluminium-zinc alloys to which 3 per cent. of copper was added showed ultimate strength as follows:

	Sand Cast.	*Chill Cast.*	*Rolled Bar.*
15 per cent. Zn	14·15 tons	14·9 tons	23·6 tons
20 ,, ,,	15·55 ,,	14·2 ,,	23 ,,
26 ,, ,,	18·25 ,,	22·22 ,,	27·92 ,,

The effect of magnesium in small quantities is, on the other hand, most decided, and from 25 to 5 per cent. magnesium has resulted in an alloy which, in rolled condition, possesses an ultimate strength of 28 tons per square inch. Light alloys are fairly permanent, if not exposed to high temperatures, although cases of deterioration have been known with alloys of approximately 80 per cent. zinc and 20 per cent. aluminium. The chief trouble is corrosion, which is marked in

the case of alloys containing copper. Indeed, the corrosion of all light alloys is hastened by contact with copper or brass when immersed. The use of light alloys in constructional work often entails welding, etc., and great care should be exercised, as these alloys are generally very sensitive to all such treatment, which may thus lead to an unexpected failure.

Certain aluminium alloys, generally known as duralumin, became materials of high importance during the war, and owe their great development to their mechanical properties. Some of these are singular and due apparently to method of tempering. Investigations were made with a duralumin of the following composition: Aluminium 93·9, magnesium 0·43, copper 3·7, manganese 0·6, zinc 0·25, silicon 0·58, iron 0·53 per cent. (some of these minor constituents may probably be regarded as accidental). Following the ordinary practice, the metal was heated to 450° C., quenched in cold water, and left to itself. The quenching itself did not seem to change the properties of the alloy to any important extent, but the breaking strength, impact strength, elastic limit, and hardness increased afterwards, within a day or two, while the elongation and reduction in area were little affected.

Aluminium alloy that is to be welded should be scraped and cleaned, and if the stock is more than $\frac{1}{4}$ inch thick the edges should be bevelled. If the blowpipe, when welding, appears too fierce a flame, then this must be reduced by (1) reduction of oxygen, and (2) an excess of acetylene. This excess of acetylene does not injure aluminium alloy, but lowers the flame temperature, which is desirable, owing to the low melting-point.

Coal-gas, instead of acetylene, mixed with oxygen would do for welding aluminium, as it is a softer flame. Often good sound welds are made with these gases, and it is very easy to fix up to the town gas; one precaution must be taken—that is, the coal-gas must be passed through an hydraulic safety valve the same as acetylene; the coal-gas is under the same pressure as the acetylene, therefore it has to be used in the same way. Also acetylene and coal-gas may be used for the same service in welding aluminium.

Before welding, articles of aluminium usually have to be heated up in the furnace to about 300° C., being covered with asbestos in the furnace. As soon as this temperature has been reached, the article should be drawn from the furnace, welded immediately, and, when completed, returned to the furnace to be reheated to 300° C., then allowed to cool till the next morning in the furnace, and kept free from air to prevent shrinkage, cracks, and fractures. Many alumin-

ium-alloy castings may be welded without preheating, such as lugs or projecting pieces broken off completely. There is a great variety of alloy mixtures, many of which are found in welding shops in articles such as gear cases, engine cases, chain cases from automobiles. It is hard to judge accurately the composition of these alloys.

It is well to stock welding-rods of three different compositions, which should be as near as can be to the same analysis as the articles to be welded. From tests the author has made, the three following mixtures can be used, and will give successful results if the articles are graded to suit them:

Aluminium	80	76	70
Zinc	15	20	26
Copper	2	3	4

In welding aluminium-alloy articles, the rod must not be pure aluminium. It must be of the same materials as the article to be welded. When welding, a flux must be used the same as for welding pure aluminium. Aluminium alloy is not a ductile metal. Hence it must be treated as one treats cast iron, and the phenomenon of expansion and contraction has to be dealt with.

Fig. 87 is an alloy gear case, which plainly tells what parts are broken and have to be made good. There are three cracks between the cylinder openings.

The first procedure on such a casting is to clean it thoroughly and free it from oil. Secondly, bevel the edges. Thirdly, prepare a piece of sheet iron and fix inside the case under the cracks. This must be larger than the cracks, to prevent the molten metal from falling through. This will enable you, too, to penetrate right through the weld. Having got this all prepared and placed on the welding table (whilst cold), and put just in the position where welding will take place, get the blowpipe, welding-rod, and flux all ready. Test the hydraulic safety valve. See that you have enough oxygen and acetylene. All being ready, and the tools at hand, place the article to be welded in the furnace, and let it remain there till a temperature of 350° C. is reached. Then remove from the furnace and place in the exact position as when cold, and immediately commence to weld. Then proceed regularly and progressively until the whole line of welding has been done, adding at the same time, as the progression takes place, equal amounts of the welding-rod to fill up level to the top of the edges, dipping the hot rod in the flux from time to time. The welding must be done quickly, and must not be gone over a second time. The tip of the flame must not be allowed to touch the

metal. Immediately the weld has been completed, it should at once be placed in the furnace again, and the temperature raised to 325° C. Afterwards it must be allowed to cool slowly, free from any draughts or air.

After cooling, the article should be examined to see if the weld has been homogeneous, and searched for any further cracks. There should not be any if the heating has been uniform. The weld should be cleaned up, or machined if required, and tested to see if it has been distorted in any way. If not, the weld is satisfactory.

If operators will follow out the instructions above, they will

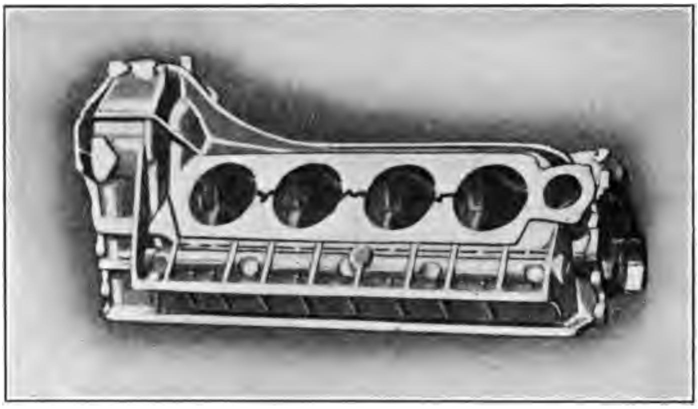


FIG. 87.—FRACTURED ALUMINIUM-ALLOY GEAR CASE.

succeed on every occasion. Each point must be watched, studied, practised, and practised time after time.

The following are important:

(1) Blowpipe must not be too powerful; oxygen at its minimum pressure; acetylene always slightly in excess.

(2) Articles must be well prepared, and placed in the welding position before placing in the furnace.

(3) Articles must be heated to a temperature of 350° C. before starting welding.

(4) Articles must not be allowed to go below the temperature of 275° C. while welding. If they do, they must be put back in the furnace and reheated to 350° C. The welding may then be completed.

(5) After welding, the article must be put into the annealing furnace, reheated to 350° C., and then allowed to cool slowly.

(6) Welding-rods must be approximately of the analysis of the welded article, and must be free from impurities.

The chief uses to which magnesium is put are, as an alloy with other metals, and for intense illuminations of short duration. When alloyed with aluminium containing one or more other metals, the crystallisation and other properties are modified. As a scavenging alloy, it clears up oxide of other alloys. Because of its intense avidity for both oxygen and nitrogen it is valuable in aluminium, nickel,

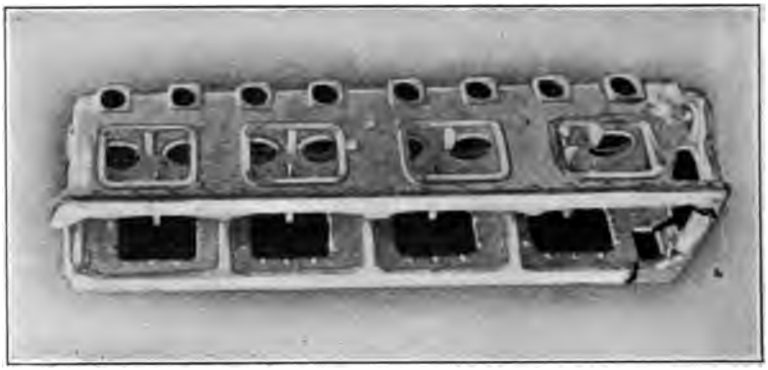


FIG. 88.—ALUMINIUM-ALLOY GEAR CASE REPAIRED

copper, brass, etc., and in special steels. In aluminium castings, for instance, less than 2 per cent. of magnesium cleans the metal, and leaves from $\frac{3}{4}$ to $1\frac{1}{2}$ per cent. in the casting, about doubling its tensile strength, quadrupling its resistance to shock and jar, and producing a much more easily machined metal.

Fig. 88 is an aluminium gear case, which had one corner of the case broken, afterwards welded successfully.

CHAPTER XXVIII

COPPER

Copper stands alone among the metals in having a reddish colour. It is capable of taking a high polish, but on exposure to the air the surface darkens considerably. It is comparatively soft (H = 3), is easily scratched with a knife, flows readily under pressure, is both malleable and ductile, and can be rolled into thin sheets or drawn into fine wire, and readily worked into any form by stamping and spinning.

It is malleable, both cold and at a red heat, but near the melting-point it becomes brittle. The tensile strength of cast copper is about 13 tons per square inch, but rods may be obtained having a strength up to 26 tons, as mechanical working, especially wire drawing, greatly increases its strength. When copper is worked, it becomes hard, and loses its ductility to some extent. This can, however, be restored by annealing. The specific gravity of copper is from 8·8 to 9 (various figures are given by different authorities), depending on its state. Castings have a lower specific gravity than sheets, and the specific gravity of the latter is lower than that of wire.

Copper melts at 1,083° C. and boils at 2,310° C. This is important to remember as, if the heat in welding much exceeds the melting-point, the copper will be burnt and full of blowholes.

It cannot be distilled. Its latent heat of fusion is about 44 and its specific heat roughly 0·094; but this increases as the temperature rises. The mean specific heat between 0° and 1° may be taken as 0·0939 to 0·00001778; the heat required to raise 1 gramme from 0° to the melting-point and melt it would be $44+(\cdot 094 \times 1{,}085) =$ 146 units. The coefficient of linear expansion is 0·00001596 for each degree centigrade rise of temperature.

Copper is an excellent conductor of both heat and electricity. Its heat conductivity is 898, and its electric conductivity slightly less than that of silver; taking the resistance of the latter as 1, that of annealed copper is about 1·003, and that of hard drawn copper about 1·086. It is necessary to say "about," because the electric conductivity is diminished very considerably by the slightest traces of

impurity. Copper can now be obtained so pure that the conductivity is considerably greater than that taken for pure copper when the standards in use were fixed. The resistance of a foot of pure copper wire, 0·001 inch in diameter, is 9·612 ohms. The conducting power, as in the case of all metals, falls as the temperature rises, the fall of conducting power being 29·3 per cent. for a rise of temperature from 0° to 100° C.

The principal varieties of commercial copper are: (1) electrolytic; (2) best selected (B.S.) tough.

Electrolytic copper is prepared by electro-deposition from solution and is usually very pure. It comes into the market precipitated in cakes $\frac{3}{4}$ inch thick, deposited on both sides of a thin plate of copper; or, after remelting, in ingots. Best selected copper is mainly used for the manufacture of alloys, as it is now prepared from pure materials. It is generally specified to contain not more than 0·05 per cent. arsenic, a trace of antimony, and no other deleterious material. Tough copper is the name given in this country to refined copper cast into slabs or billets for rolling into sheets, rods, or tubes. It usually contains from 0·25 to 0·5 per cent. arsenic, from 99·5 to 99·2 per cent. of copper, and only small quantities of other impurities.

The British standard specification for the testing of copper is as follows:

Copper Plates for Locomotive Fire-Boxes.

Tensile Mechanical Test.—A standard test-piece having a gauge length of 8 inches must show a tensile breaking strength of not less than 14 tons per square inch, with an elongation of not less than 35 per cent.

Bend Test.—Pieces of the plate shall be tested both cold and at a red heat by being doubled over themselves (that is, bent through an angle of 180°) without showing either crack or flaw on the outside of the bend.

Stay-Bolts.

The rods must be clean, smooth, uniform in diameter, and free from surface defects. The tensile test must not be less than 41 tons, and elongation not less than 40 per cent. In the hammering or crushing down test, a piece of rod 1 inch long shall be placed on end, and hammered and crushed down to a thickness of $\frac{3}{8}$ inch without showing either crack or flaw on the circumference of the resulting disc.

Copper Locomotive Tubes.

Tubes must contain not less than 99 per cent. of copper and 0·35 to 0·55 per cent. must consist of arsenic. Tubes must stand bulging or drifting without showing either crack or flaw, until the diameter of the bulged end measures not less than 25 per cent. greater than the original diameter of the original tube.

Flanging Test.—The tubes must stand flanging without showing either cracks or flaws until the diameter of the flange is not less than 40 per cent. greater than the original diameter of the tube.

Flattening and Doubling-Over Test.—The tubes must be capable of standing both cold and a red heat, without showing either crack or flaw. A piece of tube is flattened down until the interior of the two surfaces of the tube meet. It is then bent so as to be doubled

FIG. 89.—PHOTOGRAPH OF SECTION ACROSS A WELD PERFORMED WITHOUT A SPECIAL PHOSPHOR-COPPER WELDING-ROD.
Notice the numerous blowholes.

over itself, bent through an angle of 180°, the bend being at right angles to the direction of the length of the tube.

Hydraulic Test.—All boiler tubes shall be tested by an internal hydraulic pressure of at least 750 pounds per square inch.

The oxy-acetylene welding of copper is not a stupendous job, but is as easy as with any ordinary mild steel stocks, provided that the necessary instructions are carried out in the operation of welding. It is not possible to weld copper with an ordinary copper rod. The copper when melted fuses, oxidation takes place, and the metal is burnt through overheating, its temperature reaching boiling-point in the attempt to make it weld. This leaves the copper weld full of blowholes and badly oxidised, as the above illustration proves.

No matter what efforts are made to get good welds of copper, with only copper rods they would not be a success. It is necessary to have some flux to break down the oxide. The best method is to

incorporate the flux in the welding-rod, which will afterwards be diffused in the molten mass as the melting takes place. If the welding is done with a proper anti-oxidising rod, it will be quite up to the other part of the article.

The welding-rod of copper should contain a very small percentage of phosphorus, with a trace of aluminium. The phosphorus is mixed with the copper when the rods are manufactured, in small quantities, evenly distributed throughout the rods, thereby securing equal mixture in the line of welding. It is very important that the proportion of phosphorus shall not be excessive, as this causes the metal to lack fluidity, and also leads to loss of elongation. The phosphuretted welding-rod is made in all sizes, from $\frac{1}{8}$ to $\frac{1}{2}$ inch diameter (the latter is used for welding repairs in locomotive fireboxes). It is usually made in large, short, round bars, and drawn to the various sizes, which are then cut off to a length of 24 inches and bundled.

In the welding of copper articles it is usual to employ, in combination with the welding, a flux, or cleaning agent. There are several compositions of these fluxes. One very good one, which is largely used, consists of chloride of sodium 20 per cent., boracic acid 45 per cent., sodium borate 35 per cent. Another for copper alloy is: iron peroxide 35 parts, manganese peroxide 1 part, magnesium carbonate $\frac{1}{2}$ part, alum 18 parts, silica $3\frac{1}{2}$ parts, borax 4 parts. Mix and stir well. Another consists of zinc oxide and charcoal in equal parts mixed with molasses water to a stiff paste, formed into balls and then dried.

Copper welds should be prepared just in the same manner as for iron and steel; much more care and attention must be taken in cleaning the edges to be welded. If they are not well cleaned, the oxide or scale makes welding more difficult, sometimes causes adhesion, or gets internally into the weld and causes blowholes.

With thin copper sheet it is imperative to have it supported underneath. If this is not done, the metal soon runs through owing to its fluidity, and it is very difficult to stop up the hole that has been made. It is the custom in some workshops to use a thick copper plate, which, on repetition work, assists the heating of the article welded. Sometimes asbestos board is used, but the author's experience is that asbestos wants renewing too often, as the workmen seem to pull it to pieces quickly.

Further, there is a good smooth joint underneath, and welding may go right through. But in the case of asbestos, if it goes through, the blowpipe usually burns or fires the asbestos, causing

a dazzling light, and often leaves rough holes or surface on the underside.

The power of the blowpipe for copper welding should be one size higher than that used for iron and steel, but the pressure of the oxygen should be reduced to its minimum. The larger pipe is needed because copper is a very high conductor. To counteract, to some degree, this conductivity, it is very necessary, too, to heat up the copper article before welding.

The diameter of the welding-rod should be according to the thickness of the article to be welded, but slightly thicker than the same thickness for iron and steel. The minimum diameter is 16-gauge, but for general welding a stock of each size should be kept. A very good flux for copper is 2 parts cryolite, 1 part phosphoric acid. One has to be more careful in the welding of copper articles than with iron and steel, although the same procedure has to be followed out. An important point is the rapidity with which it must be welded.

Also the weld must not be gone over twice, otherwise it will be burnt, oxidised, and full of blowholes. Another point, which must be watched, is that the melting-point of copper is 1,083° C., and the boiling-point 2,310° C. This difference in temperature is vital. When the melting-point is reached, welding must be proceeded with quickly, and the blowpipe must be passed smartly over the line of welding, so as to just melt and no more. The molten copper will be in the form of a viscous, thick liquid. The addition of phosphuretted rod will make a good clean weld, with a finish as smooth as the copper article itself. There will be no oxide, no blowholes, and the weld should stand any ordinary tests.

On the other hand, if the welding is done slowly, and the blowpipe is held on the metal too long, the weld becomes too liquid by the extra heating of the metal. When the temperature is raised to a point near 2,310° C., at which the copper boils, the metal is burnt. Oxides form, which are absorbed in the metal as it cools, and cause blowholes to form throughout the weld, making it defective and useless.

Copper is the greatest conductor of heat of all metals. In welding, preheat it in a preheating furnace, if the facilities are at hand. Otherwise welding cannot proceed immediately owing to the necessity of preheating with the blowpipe to make up for the heat dispersing through the mass.

Procedure in Copper Welding.—When the article has been prepared, the blowpipe applied, and the welding-rod held in the left hand,

melting starts at one end (at the same time the welding-rod being near the flame); the blowpipe is raised slightly to impinge the flame on the rod, which melts into the molten weld and unites therein. The blowpipe still continues melting in a progressive and continuous manner. Never let the white cone of the flame touch the metal, and take care to melt, not burn, the two edges of the weld. See that the metal remains a viscous liquid, and does not become "skilly," or thin liquid. Go through to the end of the weld without increasing the melting-point. A good weld may be hammered, bent, and annealed, and will stand the tests appearing in the first part of this chapter.

The tip of the white jet of the flame should be kept $\frac{3}{16}$ inch from the metal. The treatment after welding is important, for

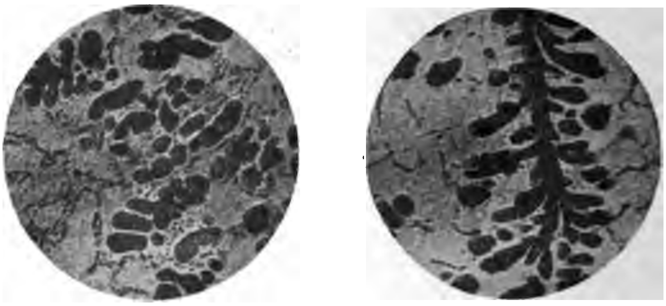


FIG. 90.—MICROPHOTOGRAPHS FROM THE REGION OF A WELD EXECUTED WITHOUT SPECIAL WELDING-ROD.

Notice the separation of the crystals of oxide (deep black). The grey streaks in the section on the right are the eutectic alloy of copper, containing 4 per cent. of the oxide.

without it the copper is inclined to be brittle. The whole article should be heated, and the weld vigorously hammered. After hammering, heat the article again to a dull red heat and plunge suddenly in cold water.

Heated copper combines with oxygen, forming what is known as cuprous oxide. This oxide is absorbed in the molten copper, under the normal action of the blowpipe, and it crystallises on cooling. When oxidised to this extent, the weld is extremely fragile. The only means of overcoming this is, as before described, the use of a proper, skilfully prepared alloy welding-rod containing a very small percentage of phosphorus.

The above illustration shows the oxide.

The phosphorus welding-rod seems to have the property of pre-

venting the formation of blowholes, either by suppressing the solution of the gases, or by aiding their evolution before the temperature of solidification. The phosphorus has the additional advantage of giving rise to a protective varnish on the surface of the molten copper. This is due to the formation of the oxide of phosphorus, which combines with the oxide of copper, forming a fusible green copper phosphate. This substance rises to the surface and protects the copper from further action of the gases of the blowpipe flame. Copper welds, when properly done, should be hammered where possible at a red heat, and then reheated and plunged in cold water. The sizes of copper phosphuretted welding-rods should be thicker than for mild steel; for instance, $\frac{1}{8}$ inch copper should have a $\frac{3}{16}$ inch diameter rod. As regards expansion, copper must be treated the same as cast iron—that is, all articles must be preheated, and annealed afterwards.

Failures in welding copper can only be caused by:

(1) Using a welding-rod of bad quality.

(2) The absence of flux when the welds are not absolutely clean

(3) Execution of the weld before the copper article is raised to a high temperature.

(4) Bad joining of the metal and irregular feeding of the welding-rod.

(5) The effects of expansion being badly opposed both during and after welding.

(6) Getting the copper to too high a temperature, greatly exceeding the melting-point.

(7) Going over the weld twice, not adding further welding-rod, thereby causing oxidation and blowholes.

There are numerous applications in which the welding process may be adopted. As regards loco fire-boxes, it has been successful in some cases but not in others. For copper tanks, bends, rods in electrical work, copper bars and rings on armatures it is being found useful. Household copper boilers are being extensively welded; and there are many other directions in which welding could now take the place of brazing.

CHAPTER XXIX

BRONZE

BRONZE may be considered as an alloy of copper and tin, the former element predominating. Alloys with 1 to 2 per cent. of tin show nearly the ductility of pure copper. They can be worked in the cold state under the hammer more readily than pure copper. The ductility decreases rapidly with an increase in the content of tin. An alloy containing 4 per cent. can only be worked with the hammer at a red heat, and soon cracks when one attempts to hammer it cold. Alloys containing up to about 15 per cent. of tin can no longer be hammered, even in a warm state. Alloys with about 9 per cent. of tin show the greatest strength of all bronzes, and those with about 15 per cent. possess the greatest hardness and strength. The maximum of hardness and brittleness lies between 28 and 35 per cent. of tin. There are various bronzes on the market, those having a percentage of aluminium, manganese, phosphor, etc., being known by a double name—aluminium bronze, manganese bronze, etc., respectively. Some of these alloys are true bronzes, as they often contain no tin.

Aluminium Bronzes.

The proportion of aluminium alloyed with copper varies from 1 to 10 per cent. The alloys are as strong as mild steel, highly malleable, elastic, and ductile. The presence of other metals impairs the quality. An alloy containing 10 per cent. has a tensile strength of 40 to 45 tons per square inch.

Manganese Bronzes.

These contain copper, manganese, zinc, and tin, and sometimes they are characterised by hardness, elasticity, and strength, combined with toughness and resistance to corrosion. They can be rolled and forged hot. An important application is for the propellers of steamships. They are also used in general engineering brass-work. The manganese is generally introduced in the form of ferro-manganese or as manganese copper.

Phosphor-Bronze.

Phosphor-bronze contains a small proportion of phosphorus, introduced either as a phosphor-tin (obtained by dissolving phosphorus in molten tin up to 20 per cent. of phosphorus) or as phosphor-copper, after fusion, or the ordinary ingredients. The tin varies from 4 to 10 per cent. and the phosphorus from 0·1 to 1. Where toughness and ductility are required the phosphorus should not exceed 0·1. Metals containing more, increase in hardness and are used for valves, bushes, cogwheels, etc. Phosphorus should be cast at as low a temperature as possible.

Silicon Bronze.

Silicon bronze contains silicon and is harder and stronger than ordinary bronze. The beneficial effects of phosphorus and silicon are generally attributed to the powerful deoxidising influence they exert on account of their affinity for oxygen. Bronzes do not absorb the heat like copper, although they absorb it more than iron and steel. There are several mixtures of bronzes, and one must be careful to use a welding-rod which is nearly the same mixture as the bronze article being welded. The table on p. 162 shows several varieties.

Welding-Rods.—Welding-rods destined for the efficient welding of bronzes must be carefully manufactured from very pure metal, and their constituents must be the same as the article to be welded, with a small addition of phosphorus and a trace of aluminium. These rods should be carefully mixed when they are made, must not contain any impurities whatever, and should be made from new materials. They are made in sizes from $\frac{1}{8}$ to $\frac{1}{2}$ inch diameter and 24 inches long. They should be sand-blasted if cast, so as to free the rods from the gritty sand.

In the welding of bronzes it is necessary to have a cleaning flux to scour the metal as it becomes molten. The flux can be obtained from chemists who are skilled in the compounding of these mixtures. A good flux for bronze is equal parts of phosphoric acid and 80 per cent. alcohol. Others are equal parts of crude tartar and nitre burned together; and 3 parts nitre, 2 parts argol.

Bronze Welding.—The first operation when one has a bronze article is to see if it is bevelled. If not, this must be done, and the weld properly cleaned and freed from all grease. It is usual to place the articles in the preheating furnace to get them hot to assist welding, and to prevent fracture from uneven heating. It is

important if the article is unsupported on the inside to support it, as unless this is done the weld cannot be penetrated right through. The power of the blowpipe must be one size higher than that for iron and steel of the same thickness. The blowpipe must be properly regulated, and the oxygen must not be in excess, otherwise the weld would be oxidised and burnt. Likewise, if the acetylene is in excess, carbonisation will occur. The blowpipe must be well regulated until a clear white cone is reached, neither oxidising nor carbonising. Attention must also be paid to the pressure of the oxygen, which must not be more than that stated by the makers of the blowpipe. This is very important.

Method of Welding.—The article should be fixed up usually in a horizontal position. If broken, the parts must be secured to prevent them from being out of line when welded. Proceed with the blowpipe (already properly regulated) to heat the edge of the line of welding, about $\frac{1}{2}$ inch from the actual edge, and start melting the two bevelled edges at this point. As soon as they become molten, add a little welding-rod, to which is annexed the flux, and then bring the blowpipe to the edge of the weld. Bring this to a molten state, add welding-rod, fill up bevel, and proceed forward with the welding, at the same time giving a regular gyratory movement. Both edges of the weld must be melted together simultaneously with the welding-rod with an occasional dip in the flux. See that the rod is kept sufficiently in the molten metal to fill up the bevelled edges to the same thickness as the article being welded. One must not go over the weld twice without adding fresh metal. If this is done oxidation takes place and the weld is full of blowholes and spoilt.

As soon as the weld is done, the article must be put into the annealing furnace and heated up to about 600° C. and then allowed to cool down slowly.

Failures in welding bronzes are due to:

(1) The use of an impure welding-rod.

(2) The overheating of the metal, making it too fluid and causing oxidation and blowholes.

(3) The weld being gone over twice, leading to oxidation.

(4) Insufficient penetration, causing adhesion.

These failures can easily be overcome if operators practise regularly, and test their pieces until they find out that they have become proficient.

CHAPTER XXX

BRASS

BRASS is an alloy of copper and zinc, and is in most general use. It should only contain copper and zinc, but most varieties contain small quantities of impurities. Copper and zinc can be mixed together within very wide limits, the resulting alloys being always serviceable.

Generally speaking, it may be said that with an increase in the content of copper the colour inclines more to golden, the malleability and softness of the alloy being increased at the same time. With an increase in the content of the zinc the colour becomes lighter and finally shades into a greyish-white, while the alloy becomes more fusible, more brittle, and at the same time harder. The physical properties of brass vary according to the relative quantities of copper and zinc. Alloys containing up to 35 per cent. of zinc can be converted into wire and sheet in the cold state only, those with from 15 to 20 per cent. being most ductile. Alloys with from 36 to 40 per cent. of zinc can be worked in the cold state as well as the hot. With a still higher content the ductility increases rapidly; and an alloy, for instance, from 60 to 70 per cent. of zinc is so brittle that it cannot be worked. If, however, the zinc is increased up to a maximum (70 to 90 per cent.), the ductility increases again, and the alloy can be worked quite well in the hot state, but not at red heat. The strength of brass is intimately connected with its composition, that containing about 28·5 per cent. of zinc showing the greatest absolute strength. The strength depends to a great extent upon the mechanical treatment the metal has received.

An important factor in brass is its melting-point, there being wide deviations in this respect, which are readily explained by the great difference in the melting-points of the two constituent metals. Generally speaking, the fusing-point of brass lies at about 1,832° F. The mixtures for certain purposes are legion.

Hot-rolling 70/30 *Brass.*—It is quite possible to roll this metal

hot by using electrolytic copper and an electrolytic spelter. The following is the mixture:

	Pounds.
Electrolytic copper	68
Cupro-manganese (25 per cent.)	2
Brunner-Mond electrolytic spelter	30

The metal rolls well at a bright red heat, but is more expensive than ordinary brass.

Admiralty Specification for Brass.

The composition of the mixtures used throughout the whole of the work supplied is to be as follows. New metal only is to be used for castings subject to steam pressure.

	Tin.	*Zinc.*	*Copper.*
Naval brass	1	37	62
Brass for condenser tubes	1	29	70

All brass subject to the action of sea water must not in any case contain less than 1 per cent. of tin.

Tensile test-pieces taken from castings must stand the following tests:

	Ultimate Tensile Strength Not Less Than	*Elongation in Length of 2 Inches.*
Naval brass round bars, $\frac{3}{4}$	14 tons	$7\frac{1}{2}$ per cent.
Naval brass round bars, above $\frac{3}{4}$ ..	26 ,,	30 ,,
High-tension brass, forged	22 ,,	30 ,,
High-tension brass, cast	28 ,,	25 ,,

Naval bars must be capable of:

(*a*) Being hammered hot to a fine point.

(*b*) Being bent cold through an angle of 75° over a radius equal to the diameter of the bars. Breaks within less than $\frac{1}{2}$ inch of the grip are not accepted.

General.—The metal castings are to be sound, clean, and free from blowholes, and no piecing, parching, or stopping will be permitted.

The above articles are often welded, and one must study their elements in order to be able to execute satisfactory welds on them.

Brasses are bad conductors, but quite as fluid as copper. There are two classes of brass—first and second qualities. The first melts at 930° C., the second at 880° C. This is important, as if they are got to high temperature they burn, the zinc volatilises, and the metal is oxidised. The melting of brass under the action of the blowpipe is accompanied by the phenomena of the absorption of gases, volatilisation of zinc, and oxidation.

Operators must not attempt to weld brass autogenously without understanding the metallurgical idiosyncrasy, otherwise success will not be obtained. Much trouble springs from the volatilisation of part of the zinc, which rises in dense white fumes. Blowholes then abound, part of the zinc is lost, and the weld has no strength.

Welding-rods for the welding of brasses are manufactured in the same way as copper rods, and should be as near as possible in composition to the metal being welded, so as to keep the same mixture of alloy as in the article itself. It is usual in shops where a variety of brass castings are welded to keep sets of welding-rods made up to the different analyses to suit the castings. These rods can be obtained from the various manufacturers who make and stock them.

Rods for brasses are made from the purest new metal, in which a minute quantity of aluminium should be evenly incorporated throughout the length of the rod. They are made in various sizes, from $\frac{3}{16}$ to $\frac{1}{2}$ inch thick. In conjunction with the rod a cleaning flux must be provided, which dissolves the alumina, prevents the volatilisation of the zinc, and protects the metal from oxidation. There are many fluxes in use, but for general purposes the following give good service:

(1)	Chloride of sodium	30 per cent.
	Boric acid	40 ,,
	Borax	30 ,,
(2)	Selenium	2 parts.
	Charcoal	1 part.
(3)	Sodium carbonate	5 parts.
	Silica (white sand)	15 ,,
	Coal dust (anthracite)	5 ,,
	Bone ash	20 ,,

Execution of Brass Welds.

The edges are prepared as for iron and steel, according to the thickness, on one side or both. If it is a case of castings, these two must be bevelled wherever the crack or break occurs, otherwise one is sure to get adhesion or lack of penetration, excessive consumption

of gases, burnt metal, and a defective weld. This bevelling cannot be insisted on too much. The bevel must be 90° to the thickness of the metal—that is, 45° each side. Brass, more than metal (aluminium excepted), must be thoroughly cleaned, otherwise adhesion takes place. Brass welds are easy to do and give good all-round results, but only when the weld line is properly bevelled and clean. Also it is advisable to preheat the article to just under 500° C.

The blowpipe used is the same as in the case of copper: one size larger than for iron and steel. The size has been selected to suit the thickness of the articles being welded. For instance, $\frac{1}{8}$ inch thick requires a blowpipe consuming 1·1 cubic feet of acetylene per hour—that is, size 2 blowpipe. The welding-rod for $\frac{1}{8}$-inch thick metal should be $\frac{3}{16}$ inch diameter.

It is essential to have a rod a little thicker than the metal to be welded in the case of brass. Many brass articles require to be supported underneath the welding line, to allow good penetration of the weld. In welding, the blowpipe should be started a little from the end (about $\frac{1}{2}$ inch), so as to preheat this part prior to doing the starting edge. When this part is beginning to become molten, just put your blowpipe on to the edge. At the same time add the welding-rod to fill and cover up the bevel, and then proceed along the line of welding, melting both edges of the article and the feeding-rod at the same time. Continue advancing with a gyratory movement and adding with regularity the welding-rod, which must be dipped in the flux from time to time, according to progress made. Welding must be continuous until the whole line of welding is complete. The welding must be rapid, far faster than with iron or steel. Care must be taken not to let the blowpipe stay too long on the weld, or it will burn, and will increase the temperature, and cause the metal to boil and bubble, which no flux or rod will check. Consequently the weld will be full of blowholes, the zinc will be reduced, and the weld will be oxidised, and therefore useless.

To avoid these failures one must not use a rod of bad mixture, nor let the blowpipe remain too long on the weld, otherwise the metal "boils." The white jet must not touch the metal within $\frac{3}{16}$ inch. Brass of the first quality can be hammered and annealed, and can stand energetic forging or stamping without showing fracture. This hammering improves considerably its mechanical properties. Brasses containing 55 to 65 per cent. of copper should be forged hot, those containing 65 to 70 per cent. of copper hammered cold. After hammering, brass should be annealed to just under 500° C.

CHAPTER XXXI

AMERICAN METHODS

OPERATORS will benefit by an insight into what the Americans are doing in the way of welding processes. Shortly after the United States entered the war, the Council of National Defence appointed an Engineering Committee, which undertook as one of its chief tasks a study of the possibilities of electric welding in shipbuilding. This Committee was taken over by the Emergency Fleet Corporation. It later broadened its scope so as to include gas and thermit welding. By its discussions, researches, lectures, and conferences, its interchange with foreign countries and its dissemination of information, the Committee gave a great impetus to the use of welding in America.

Concurrently with this work, another advance in welding, with an emphasis on gas welding, was started by the formation of the National Welding Council. With industry becoming normal, after the Armistice, it was considered desirable to extend into the entire field of joining metals, and an effective way of accomplishing this was the foundation of the American Association for the Welding Industry.

The Society was brought together in the manner usual with scientific societies: persons from all branches of the industry interested in any of the welding processes—forge welding, electric resistance welding, thermit welding, gas welding, electric spot, butt, seam, and arc welding. It will create and assist in maintaining the Bureau of Welding, which will be a separate organisation, designed to take full advantage of the principle of co-operation in research and standardisation. Some of the Society's investigations may be cited.

(1) In arc welding a determination of the best current with various sizes of electrodes.

(2) A determination of proper methods of procedure in making arc and gas welds, with a system of inspection as the work progresses.

(3) The acquirement of further knowledge of the characteristics of metal as affected by welding, particularly its ductility and its action under repeated tests.

(4) In gas, spot, or arc welding methods of assembling large structures to eliminate initial or locked-up stresses, due to contraction on cooling.

(5) The ascertainment of a proper standard for both producer and consumer. For some years numerous overlapping and conflicting efforts in the field of industrial standardisation have been carried out by more or less independent organisations, each according to its own methods of procedure. There was need, therefore, of reducing unnecessary effort, and providing uniform methods that will secure in each case the co-operation and support of all the organisations whose interests may be affected.

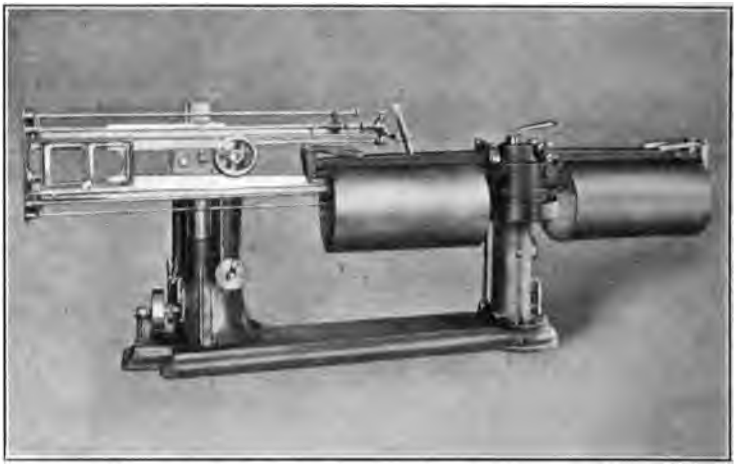


FIG. 91.—DUOGRAPH WELDING MACHINE.

Training of Operators.—The investigations of the Welding Committee have thus far shown that one of the most important elements in the success of an autogenous welding operation is the skill of the operator. To secure this, uniform methods of training are essential. The Society is taking an active part in planning how operators should be trained and how their proficiency may be determined. Some of the objects of the American Society are as follows:

(1) To advance the art and science of welding.

(2) To afford its members opportunities for the interchange of ideas with respect to the sciences and art of welding, and for the publication thereof.

(3) To conduct researches into welding, co-operating with other

societies and associations, and with the Governmental departments, for the benefit of the industry generally.

The illustration on previous page is of an automatic seam-welding machine, which is known as the "duograph." This machine, specially designed for welding the seams of drums or containers, ensuring a mechanical weld uniform in appearance and efficiency, comprises a turret-top holding device, with water-cooled arms and clamps for holding the steel drum in position, permitting of the form being placed in position for welding on the one set of arms, while

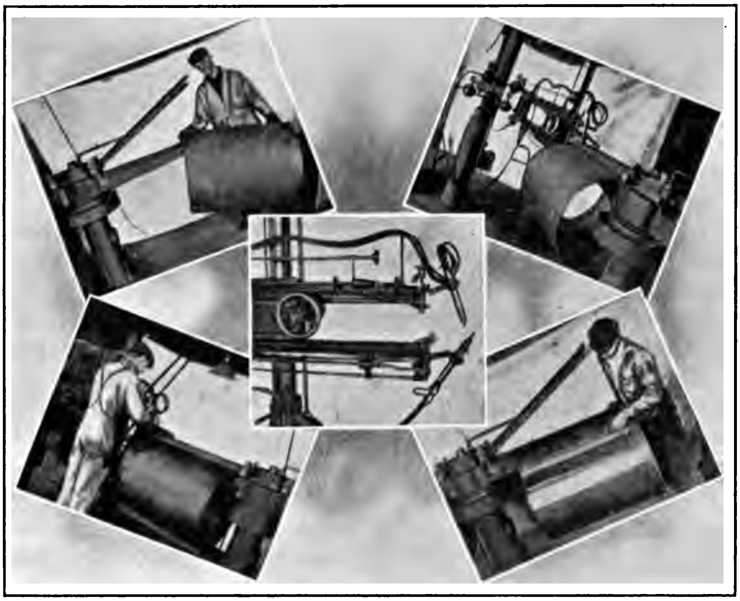


FIG. 92.—SHOWING DIFFERENT OPERATIONS OF THE DUOGRAPH.

the form on the opposite set is being welded. The turret top is then swung half-round, the welded form removed, and another set up; this preparation requires less time than the actual welding of the form in position. The blowpipe carriage is moved forward at a fixed speed of welding, by a power-belt motor driven, and is reversed by a hand wheel when the weld is finished.

Variable speed for different thicknesses of welding is obtained by the use of cone pulleys. The blowpipe carriage is fitted with two blowpipes, one above and the other below, for welding both sides of the seam simultaneously. For very light welding, one blowpipe

only is required, welding from one side. Water-cooled blowpipes are used, connected with rubber tubing to the water-supply.

This machine will weld a seam 36 inches long. An average speed of welding is 18 inches per minute, or 90 feet per hour may be obtained on 16-gauge sheets.

The photograph on p. 193 shows different operations of the duograph.

Fig. 93 is of a medium-pressure acetylene generator, 15 pounds pressure as a maximum. This is designed to provide acetylene under suitable conditions and with proper control, to meet the requirements of the oxy-acetylene welding and cutting, and to make possible the employment of the positive-pressure principle, utilising acetylene under direct and appreciable pressure, employing lump carbide for the generation of the gas, with independent power for feeding the carbide, the feeding mechanism being controlled by the gas pressure as generated: the carbide drops into large volumes of water, cools the gas, and generates slowly.

Safety has been given even greater consideration in the construction of these plants than efficiency. They have automatic feed, carbide to water, with independent power, and the quantity of carbide remaining in the hopper is constantly indicated. The acetylene gas is piped directly from the generator under requisite pressure through a service pipe-line to the welding stations, and regulated by reducing valves, fitted with pressure gauges to govern the proper working pressure.

These are made in many sizes to most economically meet the requirements of the purchaser, and may be had with capacity of 25, 50, 100, 200, and 300 pounds of carbide constituting a full charge. These generators are exceptionally economical compared with the low-pressure system. The latter are used almost exclusively in England. The blowpipes used in low-pressure consume from 1·5 to 1·3 parts of oxygen to 1 part of acetylene. The medium-pressure generators consume 1 part of oxygen to 1 part of acetylene. Hence, therefore, medium-pressure generators save 40 to 50 per cent. of oxygen over the low-pressure, also the medium-pressure gives 40 per cent. more welding. Their blowpipes never back-fire; they keep in all day. Perfect welds are obtained; no adhesion, no oxidation, fully penetrated welds with 98 per cent. tensional stresses. These advantages are attainable from the generators referred to, which are known as the Davis-Bournonville. They are built from heavy steel plates, and galvanised after manufacture. They are used in very many workshops in the U.S.A., and give every satisfaction.

This medium-pressure avoids the defects of the low-pressure types, which depend solely on the injector principle for the proper mixture of the gases imperative to securing the best results. It will be readily understood that in successful welding a neutral flame must be employed, because if there is any excess of oxygen the metal

FIG. 93.—200 POUNDS CARBIDE CAPACITY, USING $1\frac{3}{4}$ POUNDS CARBIDE. Height, 104 inches; diameter, 37 inches; weight, 850 pounds.

will be burnt and oxidised. By putting the gases under pressure instead of depending largely on the injector principle, a positive control of the gas is obtained.

Some of the most extensive work carried out in America was a twelve months' job for eleven welders, welding a metal-roofed flue,

850 feet long and 120 feet wide, constructed with 690,000 No. 9 gauge plates. This job employed 200 tons of carbide in two 200-pounds capacity generators by Davis-Bournonville Company, with 330,000 feet of oxygen and 9,200 pounds of $\frac{3}{16}$-inch thick welding-rods, for 53,365 lineal feet—or over ten miles of welding.

A notable welding job was the saving of 9,000 feet of 4 to 6 feet diameter power pipeline, averting a loss of several hundred thousand dollars, in the Colorado Mountains. The joints were leaking, and over 4,000 feet of the heaviest portion of the pipe had been discarded as impracticable; but the workmen carried on for several months during the winter.

Nearly a mile of cutting was recently done by a single Davis-Bournonville operator in Northern Canada. About two weeks' intermittent operation was required, averaging about 350 lineal

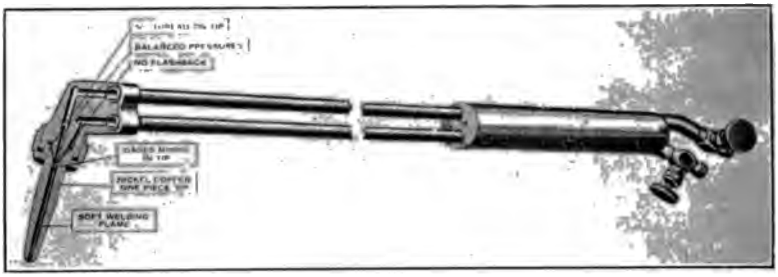


FIG. 94.—PART SECTION, NON-FLASH BLOWPIPE.

feet per day, making 5,097 lineal feet of cutting of a steel pipeline, 12 feet in diameter, 1,480 feet long. This was cut into two half-sections, and the upper half into sections for removal. The last 85 feet was done in sixty-five minutes.

Range boilers are welded at 30 feet per hour.

Barrel seams (30 inches long, by 20-gauge thick) are welded at the rate of 75 to 85 seams per day.

An immense hydraulic press was repaired at a cost of about $350, saving the owners about $1,000 per day for sixteen days.

A Corliss compound engine, 2,500 h.p., was repaired in four days. There was one crack 14 inches long, another 23 inches long, and still another 5 feet long. It was estimated that the cost of a new casting would have been $2,000, not including the cost of dismantling and reassembling; and the new casting could not have been procured in less than six weeks.

Others that would heretofore have been considered marvellous operations have been performed by the oxy-acetylene process, but sufficient has been said to convince the readers of its adaptability.

Another novel but useful tool is a blowpipe just brought out in America which is known and sold as the "rego" blowpipe. It is claimed that these torches do not, and cannot, *flash back*. This is owing to an arrangement in the blowpipe which is designed for special supply and mixing chambers. The acetylene must be higher

Fig. 95.—Air-Gas Preheating Torch Flame Playing on Mixing Chamber of Welding Torch until Tip and Nut are Red-Hot. No Flash.

Fig. 96.—Welding Torch Tip Directly on Metal at White Heat, Held There till it Penetrates. No Flash.

pressure than the oxygen, but not exceeding 15 pounds. The claim is made that this invention imparts to the acetylene a sufficient speed as it enters the mixing chamber and commingles with the oxygen to ensure that at this point, with a neutral flame burning at the tip, the speed of both gases shall be greater than that of the flame propagation of the mixtures at the point where the gases commingle.

The acetylene must be under greater pressure than that of the oxygen to obtain this result. The heating of the chamber at this point to a sufficient degree to ignite the mixed gases will not cause a "flash back," since the speed of the mixture will carry the flame

to the tip. If obstructions, such as flying particles of molten metal, or the bringing of the blowpipe close, or up to, the metal, reduce the velocity of the mixtures at the tip and tend to drive the flame into the interior of the pipe, the acetylene, being under greater pressure, immediately seals the oxygen, causing a carbonising mixture to flow from the mixing chamber to the tip and ignite. As the carbonising flame cannot flash back, the acetylene alone, or with some quantity of oxygen (depending upon the size of the obstruction), continues to burn at the tip until the obstruction is removed, when the oxygen again flows through in full volume, producing a natural flame.

The American Welding Committee of the Emergency Fleet Corporation, under the chairmanship of Professor C. A. Adams, has been

FIG. 97.—WELDING TORCH TIP DIRECTLY AGAINST BRICK. NO ESCAPE FOR HEAT WAVES EXCEPT AGAINST TIP. NO FLASH.

of great assistance to the welding industry. At the second meeting held, a communication was received from the U.S.A. Shipping Board, requesting information and advice on the most economical method of producing anchor chains in large quantities. A meeting of representatives of chain manufacturers was arranged, and the work was put in hand. In six weeks a sample was submitted. Within six months production on an order of \$1,000,000 for chains made by a new process saved the Government \$50,000 at the start. This new chain, made from cast steel, refined in an electric furnace, not only met the specifications of the carefully hand-forged chains of the past; but in place of the average production by a gang of chain-welders of the highest skill of less than 1,000 pounds per day, a foundry unit with a 10-ton electric furnace produced 70 tons of 2-inch chain in twenty-four hours, with mostly unskilled labour.

At the same meeting plans for spot welders of the portable type, for from ½ up to 1 inch plates, were discussed. Under the leader ship of H. M. Hobart, the Research Committee investigated the current density suitable for various electrodes; non-destructible methods of testing welds; the effects of locked-up stresses in welding long sections by rigid or non-rigid methods; the methods of holding plates during welding; the effect of corrosion on welds and adjacent metal, conducting a series of tests on ½-inch plates welded by employees of the manufacturers who supplied the apparatus—the choice of electrodes, current density, and method of control being left to the discretion of the welders. They finally submitted standard methods for testing electrodes for welds of all kinds, and revised specifications for electrode wire. These tests are known as the Wirt-Jones. As the result of this instruction propaganda, the Shipyard Visiting Committee reported that at Hogg Island alone hundreds of thousands of parts were being welded instead of riveted, the saving being approximately 70 per cent.

FIG. 98.—DRILLING A HOLE THROUGH. 5-INCH AXLE, TIP IN HOLE. NO ESCAPE FOR SPARKS OR HEAT EXCEPT AGAINST TIP. NO FLASH

Electric welding is used very extensively in America; the General Electric Company are extending the production of equipment for electric welding for all classes of work. I propose to show some of the equipment in general use later.

During the past few years the extension of welding of all kinds to the building and repair of ships has been phenomenal, especially as regards electric welding. While electric welding has been used chiefly for iron and steel, the technique of the art for cast iron and the various non-ferrous alloys employed in shipbuilding is being rapidly developed. The welding of copper can be done with the carbon electrode. Brass and bronze castings and flanges welded to the pipes are very common.

CHAPTER XXXII

THE METALLURGY OF ARC WELDING

We have learned to know, with a fair degree of certainty, what a steel casting should be to be acceptable for any given engineering purpose. We are apt to be very particular about casting when human life would be in danger by its failure in service. This is true of all iron and steel parts, which go largely to the make-up of our present-day necessities.

In building up and bringing together many scattered facts about the behaviour of iron and its alloys, under varying conditions, the microscope has played a very important rôle. It satisfies the natural curiosity to " see what's going on." Merely to see a line of signal flags on a destroyer, however, does not help us much unless we know what the signals mean. Just so an intelligent investigation of a metallurgical product, like a weld made by an electric arc, involves considerably more than a mere examination of the metal or its fracture under the microscope, much as this may reveal.

The making of a good weld is essentially a metallurgical problem. More specifically *an arc weld is a steel casting made by a continuous process both as regards melting and casting.* What we require is a sound, fine-grained casting, free from blowholes and slag inclusions and low in impurities. The casting must also make a continuous and perfect union with the plate or material to be welded. The physical properties of the weld will depend upon five distinct factors, namely: (1) Crystal structure; (2) gas-holes; (3) slag inclusion; (4) impurities; and (5) composition. These factors are identical with those determining the properties of any steel product, with the exception that most of the latter may be improved by heat treatment or working, while in a large majority of cases the weld must be used as made. The order in which these factors are given is not to be taken as the order of their importance; the time has not arrived when such an order can be set down.

Crystal Structure.—In studying the crystal structure of a large number of welds, as revealed by fracture, it appears that a very fine grain is produced by depositing the metal rapidly in compara-

tively thin layers, thus preventing the plate from heating up sufficiently to slow down the cooling. As soon as this occurs, columnar crystals begin to form, with a resulting brittleness.

FIG. 99.—SHOWING AREAS AT HIGH MAGNIFICATION.

It is often desirable for other reasons, however, to maintain as large a molten pool as possible. In such a case, the only way to maintain a fine structure is to hammer the weld while hot, to prevent the formation of too coarse a structure. The cooling effect

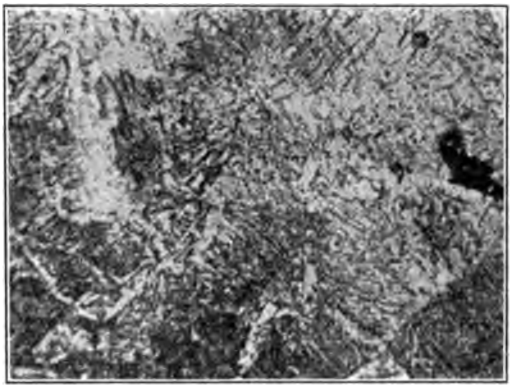


FIG. 100.—NITRIDE AREAS IN ELECTROLYTIC IRON TREATED AS FIG. 102.

of the plate upon the weld structure may be readily observed in running a short length of weld across a plate. The first part of the weld will show a fine-grained fracture, while a little farther along

CHAPTER XXXII

THE METALLURGY OF ARC WELDING

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Crystal Structure.—In studying the crystal structure of a large number of welds, as revealed by fracture, it appears that a very fine grain is produced by depositing the metal rapidly in compara-

extent. Dissolved or occluded gases in electrodes are largely liberated as the metal passes through the arc stream, and cannot have any considerable effect upon the deposited metal. They do affect

FIG. 103.—EDGE OF WELD MADE WITH COVERED ELECTRODE, SHOWING COARSENING OF GRAIN IN PLATE STOCK BY OVERHEATING. (UNANNEALED.)

the working of the electrode, however, as they cause spluttering, frequently so bad as to make the electrode useless. Experiments have shown this to be particularly true of highly oxygenous

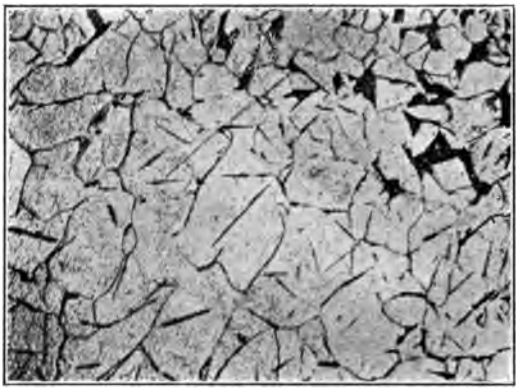

FIG. 104.—UNANNEALED WELD SECTION. WELD MADE WITH STANDARD BARE WIRE ELECTRODE.

electrode steel. Carbon is one of the worst offenders in producing gas-holes. Always ready to combine with oxygen, it finds a rich supply in the metal deposited by the arc. Carbon monoxide is

formed and, owing to the rapid solidification of the metal, *is trapped*. The carbon in the plate also becomes an important factor in this connection. The carbon in that portion of the plate dissolved

FIG. 105.—LINES IN WELD ANNEALED.

into the welding pool reacts with the large percentage of iron oxide contained therein and forms more carbon monoxide, which has no opportunity to escape. Welds made on carbon-free iron do not

FIG. 106.—SLAG ENCLOSED IN WELD.

always appear in this particular form, as may be seen where the most highly nitrogenised sections show up as dark patches not unlike pearlite. These are shown under higher magnification in Figs. 99 and 100.

Nitrogen is one of the most effective elements for making steel brittle. As little as 0·06 per cent. will reduce the elongation on a 0·2 per cent. carbon steel from 28 to 5 per cent. Nitrogen is contained in regular steel only in very small amounts, varying from 0·02 per cent. in Bessemer steel to 0·005 per cent. in open-hearth. Under ordinary conditions of fusion, nitrogen has little effect on iron, but under the conditions of the electric arc it becomes much more active. The elimination of these nitrides and oxides must be accomplished before the weld can be made ductile. Many attempts have been made to do this by the alloying of various scavengers with the electrode material, or by painting them on or in some way attaching them to the electrode. Among other impurities that may occur in a weld, the sulphur may combine with the manganese present.

It is doubtful if enough sulphur will remain in the weld section to do any great harm. Phosphorus forms a dangerous phosphide eutectic with iron, which tends to form a brittle envelope around the crystals.

Composition.—By composition, given as the fifth item influencing the quality of the weld, is meant the intentional addition of such elements as nickel, tungsten, or the like. These elements in varying proportions are added to steel to impart specific properties. One other item which must receive consideration is the effect of overheating the plate during welding. In all welds on fairly heavy sections, this effect is always present, and not infrequently so weakens the metal as to cause it to break just outside the weld, giving rise to *mistaken ideas that the weld is better than the metal welded.* This overheating causes a coarsening of the grain in the metal (see Fig. 103), and the segregation of the pearlite into large masses enclosed in ferrite envelopes. In general, it must be said that much depends on the operator, and much difficulty is experienced on this account in comparing data from several sources. Great difference of opinion still exists on many of these points, but the co-operation of the welding interest is making rapid strides towards placing the whole art upon a more scientific basis.

CHAPTER XXXIII

BRIEF DESCRIPTION OF ELECTRIC WELDING

ELECTRIC butt welding is a method of fastening together suitable pieces of metal by the creation of intense heat at a desired place through the proper application of electricity, jointly with pressure if butt, seam, or spot welding. The pressure must be applied—if the work is to be efficient—in increasing ratio, before and after the application of the electric current. The time taken to make a weld varies from one-fifth of a second to four or five minutes, according to the area welded. The current required is of high ampèrage (*i.e.*, volume), but at low voltage (*i.e.*, pressure).

Volts × ampères = watts.
1,000 watts = 1 kilowatt.
746 watts = 1 horse-power.

The pressure is applied by hand or foot, by spring, or by hydraulic means, according to the nature and size of the work to be welded. There is no danger. The voltage or pressure used in the electrodes and the exposed portion of these machines is so low—being from only 2 up to, possibly, 5 volts at the most—that no one would feel an embarrassing shock therefrom. It is about equivalent to the voltage or pressure of an ordinary push-bell. Subsequently, heat has no effect upon the weld, unless the heat is of such an intensity as to remelt or burn the metal; no less degree of heat will affect it.

There are four main divisions of electric welding, namely:

Spot Welding.—This, as its name implies, is a process which consists in welding articles together in spots instead of riveting them. The spots are usually $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter, seldom larger.

Seam Welding.—This is a process whereby the overlapping edges of metal are joined together by fusing.

Butt Welding.—This process consists in bringing together, or butting, the two ends of the metal rod, bar, etc. (not overlapping), thereby causing them to fuse one into the other.

Arc Welding.—This process is used for filling in new metal along the joints to be welded, the electric current melting both faces to

be welded at the same time as the electrodes, and filling up the joint to the level of the plate.

In spot welding the electrodes on various machines may vary from $\frac{5}{8}$ to $\frac{7}{8}$ inch or more in diameter. They should be tapered similarly to a pencil, at an angle of about 45°, to a dull point. The point should be slightly less than the diameter of the weld. This may cause a marking or pitting of the metal where the weld takes place, which can be avoided on the mild steel about 20- to 28-gauge by using flat electrodes on one or both sides. On thicker materials one flat electrode can be used.

Relative Cost of Riveting and Electric Spot Welding.—Riveting requires, in labour, the marking off, punching, and drilling of both the plates so that the holes match, and the actual operation of riveting. Then there is, of course, the purchase cost of the rivets. The result attained is two pieces of metal held together by a softer metal. As they are held chiefly by the pinch between the two rivet ends, working is likely to take place, for the rivets seldom fit the hole tightly.

Spot welding saves the cost of rivets and most of the labour. There is no marking off, no holes to punch, no rivets to fit in the holes. The welds can be applied at a speed varying, in continuous succession, from a few to over 100 per minute. In fact, on certain kinds of work, 200 welds can be applied per minute. The welding machines on light work are capable of making a weld every fifth of a second, the speed depending upon the ability of the operator; and in all repetition work the spot welding costs are 75 per cent. less than riveting.

Metals Suitable for Spot Welding.

Platinum to steel or iron.
Silver to brass, steel or iron.
Aluminium.
Phosphor-bronze to self and brass.
Brass to self, steel, and iron.
Copper to self, with a thin brass insertion.
Steel to self, iron, and metals as above.
Iron to self, steel, and metals as above.

Cast iron is not weldable by this process.

Butt welding is principally used for repetition work, joining together bar metal for crankshafts, drop forging, to stock bars, tyres for cars and waggons, bands for oil drums, rings, chains, mild steel to high-speed steel, etc. The scope is from wire the thickness of hair to 15 inches square.

Seam welding is used for making watertight joints, where spot

welding would not suffice. Seam welding consists of welding together the overlapped edges of two sheets of metal by heating under pressure, with copper rollers or wheels.

Usually the combined effect of the pressure and the heat causes the welded seam to be nearly the same thickness as the original stock. It is, however, limited in its application to thinner material, and aluminium cannot be welded.

Early in 1902 there was a demonstration in Milwaukee of the use of the electric arc for the cutting of steel. An enormous boiler foundation had to be removed from the basement of a building, so heavy that local mechanics despaired of being able to cut it. The electric arc was requisitioned and soon cut (or, more correctly, burned) the steel plate at the rate of 1 foot in five minutes, so that in a short time the whole plate was divided in blocks and transported away.

Electric track welding has become an important business. Rail joints are welded together just as they lie on the ties. The first operation is sand-blasting to free the rail ends from dust and dirt. An apparatus resembling a horseshoe is placed over the rails where they join; then, strips of steel having been placed on the sides of the joint, the current is turned on. The metal of the joint soon rises to a welding heat. The current is next shut off and the hydraulic jaws produce a great pressure which completes the weld quickly. The current used is from 25,000 to 30,000 ampères at 7 volts. The supply at the welder is regulated at about 30 volts.

Operators often ask, What is a volt? This is a term used to represent the pressure of electrical energy. In steam we would say that a boiler maintains a pressure of 100 pounds. This term relates to pressure only, regardless of quantity, just as the steam pressure of a boiler has nothing to do with its capacity.

An ampère is a term used to represent the current. In the case of steam or water we speak of the carrying capacity of a pipe in cubic feet, while in electricity the carrying capacity of wires is given in ampères.

A watt is the electrical unit of power, and equals volts × ampères. One watt horse-power is equivalent to $1\frac{1}{3}$ mechanical horse-power A kilowatt-hour, or k.w.h., is the electrical equivalent of mechanical work, which would be stated in the latter in the terms of horse-power. It means the consumption of 1,000 watts of electrical energy steadily for one hour or any variation thereof (such as 5,000 watts for twelve minutes), and it is the unit employed by all power companies in selling electrical power, their charges being based on a certain rate per k.w.h. consumed.

K.v.a. means kilovolt ampères, or volts × ampères ÷ 1,000. In any inductive apparatus, such as a motor or welding machine, a counter current is set up within the apparatus itself. This makes it necessary for the generator to produce not only ampères enough to operate the motor or welding machine, but also enough in addition to overcome this opposing current, although the actual mechanical power required to run the generator is only that sufficient to supply watts or electrical energy (volts × ampères) actually consumed in the welding machine. Hence the k.w. demand of a welding machine represents the actual useful power consumed for which you pay, while the k.v.a. demand represents the volts × the total number of ampères impressed on the welding machine ÷ 1,000, to overcome also the induced current set up within it. But it is the k.v.a. demand that governs the size of the wire to be used in the connecting up of the welding machine. K.w. divided by k.v.a. of any machine is usually expressed in percentage.

According to a report submitted to the Convention of the Association of Railway Electrical Engineers, and reprinted in the *Railway Review*, December 2, 1916, $\frac{1}{8}$-inch mild steel electrodes used for welding 2-inch flues require a current from 60 to 90 ampères, with a voltage from 14 to 16; 5-inch flues using a $\frac{5}{32}$-inch mild steel electrode require a current of from 110 to 140 ampères, with a voltage of 16 to 20. Mild steel electrodes $\frac{3}{16}$ inch thick require a current of from 151 to 180 ampères, with voltage from 18 to 25 volts. When carbon electrodes $\frac{3}{4}$ inch thick are used for cutting, a current is needed of from 250 to 370 ampères, with a voltage of 35 to 50 volts. In some outfits, however, carbon electrodes much smaller in diameter are used, one company employing only $\frac{3}{16}$-inch diameter.

When very thin sheet is welded with metallic electrodes with low current values. The following data for sheet metal are based on the cost of labour at 1s. 6d. per hour, current at 1d. per kilowatt-hour. Metal No. 20 gauge, metal electrodes $\frac{1}{16}$-inch diameter, current 10 to 25 ampères, speed 30 feet per hour, average cost $\frac{3}{4}$d. per foot. Metal 18-gauge, metal electrodes $\frac{1}{16}$-inch diameter, current 35 to 40 ampères, speed 28 feet per hour, average cost $1\frac{1}{4}$d. per foot. The cost of welding $\frac{1}{4}$-inch thick plates by the arc welding method is about 50 per cent. of the cost of welding by oxy-acetylene on similar plates. To weld plates $\frac{1}{2}$ inch thick by arc welding will cost 40 per cent. less than oxy-acetylene. On 1-inch thick plates arc welding is 15 per cent. cheaper than oxy-acetylene, but the latter is better in regards to expansion owing to slow heating, which leaves small granular section.

The electric arc claims superiority over some of the other methods. First, the high temperature of the electric arc makes it possible to reduce rapidly to a molten state the metal to be welded. The heat being applied rapidly is not being carried away from the point of the weld by the heat conductivity of the metal fast enough to lower the temperature at the weld appreciably. Secondly, the tools for performing the weld are comparatively easy to manipulate. The apparatus required is simpler than that used for gas outfits. Thirdly, for all work, except very thin materials, it is cheapest. Fourthly, the voltage of the current is so low that the process is perfectly safe. If the operator is provided with a proper hood or shield to protect him from the light and heat of the arc, he is not exposed to any danger. The heat and light from the carbon arc are much greater than that from a metallic arc.

The greatest advantage of all, probably, is that the welds can be made overhead and on vertical seams by the metallic arc. The arc actually carries the metal particles from the electrode into the weld with considerable force, so that even with an overhead weld the metal is forced clear through the space between the adjoining surfaces, welding them securely. Overhead welding cannot be done so easily by any other means. The welds that are most commonly welded by the electric arc are mild steel, and steel castings. For mild rolled steel and steel castings, electrodes or filling rods of soft iron, preferably Swedish iron, are used. Tool steel may also be welded with Swedish iron electrodes. Copper has been welded to steel by using a copper-phosphor rod. Brass also can be welded with a brass-aluminium rod, bronze with a bronze-aluminium rod.

It is not possible to weld aluminium, cast iron, or copper with much success, although attempts have been made. These metals are best left to the oxy-acetylene process, with which a good weld can always be made.

CHAPTER XXXIV

ELECTRIC ARC WELDING

ELECTRIC arc welding is a fusion process, and as is the case in the oxy-acetylene blowpipe system, the joint or weld is obtained by the autogenous union of the metal. The two pieces are united by filling new material between them, the electric current melting both faces to be welded, while at the same time the new metal of the electrode melts into the junction of the two. The quasi-arc process is dependent upon an entirely new phenomenon brought to light by investigation, and is so different in method and result from the arc fusion process that it merits being put in a class of its own. Not only is this new process much more rapid than any existing method, but it produces a perfect joint, owing to the fact that the heat introduced into the weld is automatically governed by the nature of the special electrodes employed. There is no limit to the size of the work which can be welded, no expensive plant or machinery is required, and the current consumption is extremely light.

In this process the highly localised heating agency of the electric arc is employed to bring about autogenous union. The fusing starts immediately the arc is struck, but under such conditions that throughout the whole operation the fused adjacent metal is entirely protected from all oxidising influences. The result is obtained by the use of patented electrodes in conjunction with the patented method of application. The method of application is rendered possible by the special character of the covering employed for the electrodes, and eliminates the necessity for particular skill on the part of the operator, which is an essential feature of other fusion processes. Uniformly good and reliable results are obtained, and no appreciable thermal disturbance is caused to the structures of the surrounding metal. It is necessary, when preparing the weld, to have both edges of the line of welding bevelled if it is over $\frac{3}{61}$ inches thick.

The importance of forming a joint which shall contain no trace of oxide is so great as to deserve particular emphasis. Not only does the presence of oxide greatly reduce the strength of the weld, but

it renders the joint peculiarly liable to corrosion. But for the general welding in engineering works, shipyards, and steel foundries the only requisites, beyond the electrodes, are a simple electric holder, a supply of current, either direct or alternating, at a pressure of about 105 volts, and a suitable resistance for regulating the current. Should, however, direct current be available, this may be used provided that a reactance coil is installed in each welding circuit.

The bared end of the electrode, held in a suitable holder, is connected to one pole of the current supply by means of a flexible cable, the return wire being connected to the work. In the case of small articles the work is laid on an iron plate or bench, to which the return wire is connected. Electrical contact is made by touching the work with the end of the electrode held vertically, thus allowing the current to pass and an arc to form. The electrode, still kept in contact with the work, is then dropped to an angle, where the arc is immediately destroyed, owing to the special covering passing into the igneous state, and as a secondary conductor maintaining electrical connection between the work and the metallic core of the electrode. The action once started, the electrode melts at a uniform rate, as long as it remains in contact, and leaves a seam of metal perfectly diffused into the work. The covering material of the electrode, acting as a slag, floats and spreads over the surface of the weld as it is formed. The fused metal, being entirely covered with the slag, is thereby completely protected from all risk of oxidisation. The slag covering is readily chipped or brushed off when the weld cools, leaving a bright, clean metallic surface.

During the last two years much attention and investigation has been carried out on the problems involved in the application of the process to ship construction, with a view to the substitution in a large measure of quasi-arc electric welding for riveting. The investigation has been of a twofold character: firstly, by a series of exhaustive tests to determine the relative strength of quasi-arc welding under all conditions of stress and of various types of joints; and secondly, to determine what modification of design would be necessary or desirable where welding is adopted. The results of these tests, set out in the following pages, establish the fact that a weld by this process is not merely as strong as, but is, in fact, substantially stronger than, a riveted joint, while the various modifications in design which have been evolved and patented by the Quasi-Arc Company effectually overcome many difficulties experienced in present practice in ship construction; and this,

coupled with a notable saving in weight of steel used. Inasmuch, also, as the work of one welder is approximately equivalent to that of a squad of four riveters, there should be a substantial increase in the rate of production, accompanied by economy in total cost.

In order to test the strength and suitability of a welded joint, it is not sufficient to be content with a mere tensile or bending test; a joint which could satisfactorily pass such tests might give a very poor result when an alternating or vibratory stress is applied—indeed, from the point of view of ship-designers, the latter is probably of greater importance than either of the former, and for this reason special attention has been given to the matter. The joints welded by different processes may give approximately equal tensile results, but show a marked difference when subjected to alternating stresses. Hence the importance of the adoption of such a process of electric welding, and electrodes of such standard quality, as will amount to a guarantee that a true crystal union actually takes place.

The coatings may be of such a nature as to supply constituents that are burnt out in the metal in welding, and so compensate for their loss. In some electrodes aluminium wire is incorporated under the coating. Blue asbestos yarn is specially preferred as a coating for the electrode for welding mild steel and iron, as it is a reducing flux and may be smeared with a composition such as sodium silicate or aluminium silicate, to the very fusing temperature of the yarn. Extreme care is used in preparation of the electrodes, and much stress is laid on the good and regular quality of the metal of which they are composed, and upon the exactness and evenness of the coating. The metal electrode is positive to the work and, in fusing, is deposited upon it. The coating in melting forms a vitreous slag which covers the weld and flakes off more or less in cooling. The slag must be carefully removed if successive layers are required. The object is to protect the weld from absorbing oxygen and so avoid deterioration of the quality of the metal in the weld. The metallic electrode fuses into the joint prepared by bevelling the edges of the pieces to be welded, so that there is not properly an arc. The electrodes vary from 14 to 4 s.w.g. in diameter for ordinary work up to ¾-inch thick. The current is direct, and the voltage recommended is about 100, but much lower in ampères than with Bernodos' system, varying from 20 to 75 ampères according to the thickness operated upon.

Cutting is impossible with a metallic electrode. The electrode melts away in the operation. If it touches the work it sticks to it.

Occasional cooling by dipping the electrode in water is necessary. A carbon electrode is more easily manipulated for this purpose With the metallic electrode positive to the work, welds can be made upwards—that is to say, the operator can work underneath the article, and weld its under surface. This requires a particularly good operator.

Many tests have been made, both in the laboratory and in practical service, and their utility has been fully demonstrated. The work, however, must be designed to suit the process, and the process must be regulated to suit the work, in order to attain success.

Industry in wartime becomes founded on an entirely new process: production and speed of manufacture become of first importance; the cost becomes, to some extent, secondary. New methods must be introduced with a rapidity unknown in peace-times, and the taking of some chances becomes an absolute necessity. The desirability of avoiding machine work and of reducing to a minimum the labour item, the necessity of utilising unskilled labour wherever possible, all become of great importance. The necessity for long life is not always present; substitutes must be found for many materials where a shortage exists, and margins and factors of safety must be reconsidered and, wherever possible, reduced.

The steel industry with its allied and auxiliary developments naturally becomes of first importance. The uses of iron and steel in wartime as well as in times of peace are so manifold as to preclude a detailed listing. In practically all the uses of steel several parts must be joined together to form a whole, and in many of these operations rivets have been the means of union employed. In the building of ships, in the construction of all structural material, wherever steel plate is used, and in places without number, the rivet has been the means of union between the two separate steel parts. In accordance with the law of economics, wherever a process can be performed in such a way as to show an advantage in quality, speed, cost, or quantity, it must supplant other methods. Electric welding, in some forms, gives every promise of replacing riveting in the enormous field which the latter has long held for its own. It is only when a rival appears upon the field that the characteristics and claims of a process are properly investigated.

Electric welding is not a new art, but in its various forms has been used for many years. To those who have studied the subject, the possibilities of arc, spot, butt, and other forms of welding are well known. The results that can be obtained are matters of ex-

perience, and years of actual service have sufficiently demonstrated the unquestionable reliability of the process. The careful and elaborate scientific investigations now under way to determine the characteristics and limitations of all the forms of electric welding will soon place knowledge of the art on a broad basis comparable to that of our best engineering methods. The repair of the wilfully damaged German ships has been one of the most spectacular demonstrations of the possibility of the welding art.

In those industries in which iron and steel parts are employed there is practically no limit to the opportunities for employing electric welding. In salvage and repair work it is being rapidly introduced. Ships, ships, and more ships was an urgent and familiar war cry, yet peace does not release us from building ships. In the course of a few years we may hope to see the electrically welded ship the rule instead of the exception.

Arc welding is relatively slow, requiring more labour, but the apparatus is lighter and more portable. Electrodes for arc welding cost approximately 4d. to 6d. per pound bare, and from 10d. to 3s. per pound flux-covered. There is a wide range of chemical compositions, from almost pure iron and steel with high manganese, fairly high carbon. It is certain that, where the strength and ductility of a weld are important, thoroughly skilled operators are necessary, and these cannot be ordinarily produced with less than six or eight weeks' training.

With the introduction of electric welding in shipbuilding comes the necessity of devising new methods of assembly and holding the plates in position for welding. Several methods have been proposed, but their success can only be demonstrated by actual experience. The author suggests a powerful magnet (such as one lifting iron plates in steel works) for holding the plates while they are tacked. This would save bolts and the need of bolting. The magnet could be moved from place to place by shutting off the current. Dependable arc-welded joints can be made with an average strength of over 90 per cent. of the plate strength, when backed up by butt straps with an average strength of over 100 per cent. Owing to the relative brittleness of arc-welded joints, much fear has been expressed as to their ability to withstand long-continued vibration stresses and shocks. Welding affords the most simple and effective means of making joints in steel plates capable of holding, without leaks, the warm oil which the tanks contain in service. The use of welding has lowered the cost of tank-making very materially, and has reduced the amount of noise

in the tank-shops, thus making the tank-maker's job more agreeable.

The apparatus required for electric welding is comparatively simple and very durable. When once it is installed, the operator requires only his electrodes, and a source of electrical energy. A successful operator must be a man of honest temperament, conscientious, and interested to obtain the best results. He may be taught in a few days to hold the arc steady; in about three months he may become an average operator. It requires some time to acquire the skill necessary to produce fairly uniform results in the different positions in which welding must be done. The operator must acquaint himself with the flow of the metal, in order to know definitely whether the current which has been selected for welding is too high or too low; he must come to know if the plates being welded are penetrated enough with the arc to form a good joint; he must observe the movement and the condition of his work, so that he can leave the least possible strain in the completed weld. These and many other points are to be learned principally through experience.

Preparation of the Work for Welding.

It is essential that the work be properly prepared before welding is begun. A thorough study must be given to the job in hand before any attempt is made to weld. This study must be first applied to the effect of heat on the parts to be joined; secondly, to the accessibility of the parts to be welded; thirdly, to the nature of the strains to which the weld will be subjected; fourthly, to the cleaning and assembling of the parts; fifthly, to the position in which the weld can be made; and sixthly, in what condition the weld is to be left when finished.

(1) The effect of heat is to produce expansions and contractions which must be provided for wherever possible, otherwise severe strains may be left in the plates and welds that will materially reduce their effective strength or leave the work in a warped and distorted condition.

(2) The parts to be welded should be made accessible, so that the welding may be performed thoroughly and the work of the operator simplified.

(3) A study of the strains to which the work will be subjected is necessary in order to determine the kind of weld that should be used. Different kinds of welds will be required according as the strain is a direct tension, bending, torsion, prying, compressive, or

a composite one; and as the strength must be great, as in a main seam, or small, as in a caulking weld.

(4) The cleaning and assembly of parts must be such as to provide clean, proper, and sufficient contact surface for the welded-in portion, and so arranged that a good and substantial joint will result.

(5) Wherever possible, the joint to be welded should be placed in

FIG. 107.—USE OF METAL ELECTRODE IN WELDING STEEL BANDS TO PRESSED CORRUGATIONS.

a position which will be the least arduous for the welder. Under this condition he will naturally do his best. Such a position is usually in the horizontal plane. Vertical and overhead welding may be done, and done well, but these positions are more difficult and tiresome for the welder.

(6) Usually the "welt," or raised portion of the weld, is left on. But it is sometimes necessary to remove this and have a plane surface; for example, round the top of a tank which is to have a special

finish the entire raised portion of the weld may be removed. Under these conditions a light reinforcing weld may be made on the seam inside the tank to compensate for the metal that has been removed.

It is important, if the weld is to be made continuously in one layer, to allow for a contraction of the joint as the weld progresses. Unless this is done, undue warping and excessive internal strains may result. The amount of this contraction varies slightly with the

FIG. 108.—USE OF CARBON ELECTRODE WITH METAL FILLER WHEN WELDING $\frac{1}{4}$-INCH THICK STEEL BASE TO THE EDGES OF PRESSED CORRUGATIONS.

speed at which the work is done, and is about $1\frac{1}{2}$ per cent. of the length of the weld. Clamps are used to hold the plates the proper distance apart, and these are gradually released as the weld approaches them. The operator watches the opening. If it closes too quickly, he hurries his welding. If it does not close quickly enough, he waits for it. These precautions need not be taken in very short butt welds. Such welds are too short to develop any serious strains.

Welding with Metallic Electrodes.

Many of the accompanying illustrations show samples of metallic electrodes welding work in tank-manufacture. These indicate that a great variety of work can ably be done by arc welding with metal electrodes, and show that such operations are thoroughly practicable, and the results neat and substantial.

FIG. 109.—SEAM PREPARED FOR HAND WELDING WITH CARBON ELECTRODE AND OPERATOR IN POSITION FOR WELDING.

Welding with Carbon Electrode.

The method applied to light corrugated tanks differs from those used on boiler plate tanks. The sheet steel of these corrugated tanks is principally of $\frac{1}{16}$ and $\frac{3}{32}$ inch thick and the carbon electrode is used primarily to fuse together the upturned edges of the sheets. The carbon electrode is also used in conjunction with a metal filler when placing the $\frac{1}{4}$-inch bottoms in the corrugated tanks. The metal electrode, also, is used on these tanks when welding the band to the corrugations. Welding, as applied to corrugated construction, is graphically portrayed in the illustrations of these tanks.

Electrodes.

The bare electrodes that have been found satisfactory for tank construction are as follows:

(1) Norway or Swedish iron.
(2) Toncan iron.
(3) Armco bright hard-drawn electric welding wire.
(4) Roebling bright hard-drawn electric welding wire.

These wires and the tank steel have the following analyses:

		Steel Plate.	Steel Wire.			
			1	2	3	4
Carbon	per cent.	0·25	0·049	0·10	0·078	0·185
Manganese	,,	0·40	0·021	0·16	0·041	0·561
Phosphorus	,,	0·025	0·025	0·025	0·010	0·032
Silicon	,,	0·000	0·08	trace	0·000	trace
Sulphur	,,	0·028	0·08007	0·046	0·032	0·038

A satisfactory welding wire will melt and drop small particles uniformly into the weld.

If there is considerable spluttering, and large globules drop from the welding-rod, the weld will be very porous, and the deposited metal will be poorly united to the plates being joined.

It is difficult to give universally applicable figures covering ampères, speed, etc., for electric welding, owing to the effect of conditions under which the work is done, the character of the work, and, to a very large extent, the skill of the operator. The following figures are based on favourable working conditions and a skilled operator. They are approximations only, and are given merely as a general guide.

METALLIC ELECTRODE WELDING.

Electrode Diameter in Inches.	*Ampères.*	*Corresponding Plate Thickness in Inches.*
$\frac{1}{4}$	25 to 50	up to $\frac{3}{16}$
$\frac{3}{16}$	50 ,, 90	,, $\frac{1}{4}$
$\frac{1}{8}$	80 ,, 150	$\frac{1}{8}$ to $\frac{3}{8}$
$\frac{5}{32}$	125 ,, 200	$\frac{1}{4}$,, $\frac{1}{2}$
$\frac{3}{16}$	175 ,, 225	$\frac{3}{8}$ and up

The same size electrode may be used with various thicknesses of plate. The heavier plates will require heavier currents. Approxi-

mate speeds of welding sheet metal with metallic electrodes and oxy-acetylene welding are given in the following table:

Thickness of Plate.	*Speed, Feet per Hour.*	*Cost per Foot of Electric Arc Welding.*	*Comparative Cost per Foot of Acetylene.*
$\frac{1}{16}$	20	2·12	1·78
$\frac{1}{8}$	16	3·12	4·66
$\frac{1}{4}$	10	7·13	12·3
$\frac{3}{8}$	6·5	12·3	36·1
$\frac{1}{2}$	4·3	19·8	much higher
$\frac{3}{4}$	2	41·7	,,
1	1·4	61·3	,,

Any direct source can be used for welding, but the voltage of the arc must be reduced to values of from 50 to 20. The G.E.C. have

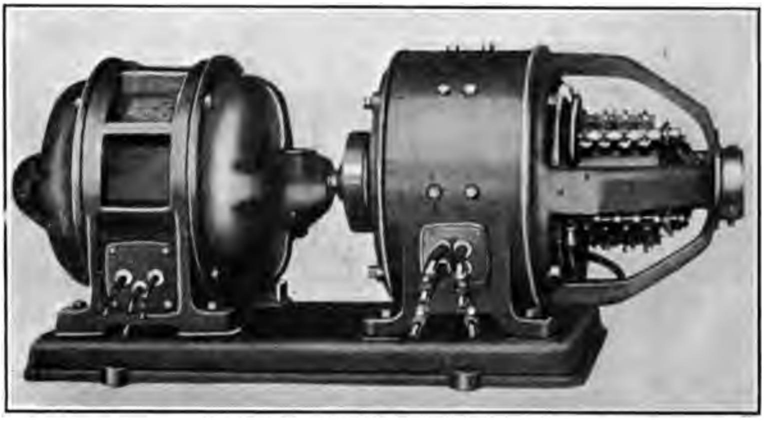

FIG. 110.—COMPLETE UNIT FOR ELECTRIC ARC WELDING.

developed a special line of low-voltage generators and controls, which give a very good efficiency, combined with flexibility and ample protection. The generator is wound for a voltage of 60 to 75. In no case is it necessary to have a generator of higher voltage than this. Lower voltages may occasionally be used with low circuit values. The generators are usually furnished as a part of a motor-generator set, although they can be supplied for a belt drive if desired. The motor-generator set is the most desirable equipment for several reasons: it is a self-contained unit and does not demand any attention when running; the maintenance is low; the weld-

ing circuits and the shop circuits are electrically independent, so that short circuits in the welding circuit will not seriously interfere with the shop circuit; the voltage on the welding circuit can be regulated, if desired, by adjustment of the generator field rheostat. The control equipment consists of a main generator panel, with or without a welding control circuit, with a separate auxiliary panel for each operator. The equipment mounted on these panels is shown herewith. In addition, there is, in series with the arc, a grid rheostat for varying the current by means of a dial-switch shown on the panel.

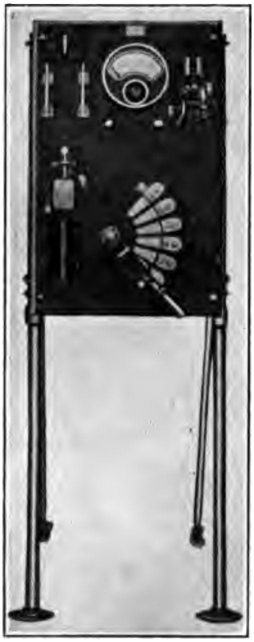

FIG. 111.—WELDING PANEL.

Setting of the dial-switch determines the amount of resistance in series with the arc.

The automatic control equipment gives thorough protection to the generator without affecting other operators whose welding circuits may be connected to the same generator; this equipment consists of a protective relay controlling a shunt contactor in the welding circuit. The setting of the dial-switch on the welding panel determines the amount of resistance in series with the arc, and therefore controls the current used. This is regulated by the current required by work done. Before starting the arc the operator must set the dial-switch for the amount of current required, so that on starting the circuits are in normal running position. There is no necessity for having any relays or switches open or closed, or in any way changing or disturbing the electrical circuit in order to weld.

Where welding by the carbon electrode is to be done, thin metal can be welded using 150 to 250 ampères. Medium welding by this process requires from 250 to 350 ampères. Heavy welding will require 400 to 600 ampères. Where cutting is to be done by the carbon arc, the capacity of the set depends on the cutting speed required. For light metal where speed is not important, 300 ampères are sufficient, but where the metal is 2 inches thick or more it is desirable to use heavier currents. For this purpose up to 1,000 ampères can be used.

In addition to the equipment and accessories previously described, special jobs render it desirable to have on hand other miscellaneous pieces of equipment. Odd pieces of copper and carbon blocks are

of much assistance as " dams " in holding the metal in place. In cases where the weld must be smooth on one side, a piece of copper or carbon is held against the weld, and the metal filled against it. Iron and steel can be used if care is taken not to weld it. In filling a hole, the bottom is often closed by holding a plate of copper or carbon against it until sufficient is filled in. Care should be taken to flow the molten metal against the guide-pieces, not to allow the arc to play directly on them. Otherwise the weld will probably become contaminated by this material, or else the guide-pieces may be welded solid and not easily removed. A steel wire scratch-brush is used to remove slight scale and rust before commencing the weld, also at intervals during welding—as when changing electrodes. For small work the positive lead may be bolted to an iron plate, forming the top of a work-bench. The work may be set on this bench, the contact being sufficient to carry the current. In many cases a vice mounted on the table will be found useful.

If the work is too large for the table it may be set beside the table and a bar laid across it. This will provide sufficient current carrying capacity, providing that scale and rust do not prevent contact. A convenient terminal for the positive cable consists of a copper hook of proper size, to which the cable is bolted. If welding is to be done in a room where other employees are doing different work, screens should be provided around the welding operator. They should be high enough to prevent the light striking a large part of the ceiling, since the flicker of this light would probably affect other workmen. The effect, while probably not injurious, would be irritating. White walls and ceilings should be avoided in a welding room. Gas-burners or annealing furnaces for preheating fire-bricks, sand, or asbestos sheeting for covering are useful, especially in cast-iron work, which in many cases should be preheated uniformly to a red heat and welded at that temperature. A receptacle of water is desirable in which the electrode holder can be cooled when it becomes too hot after continual use.

Some operators feel that gloves are necessary to protect the hands from the arc. In many cases, however, the operator finds gloves to be in the way, especially when working with a metallic electrode. If desired, however, any leather glove will give sufficient protection to the skin of the hands, which is much less sensitive than the skin on the other parts of the body. The arms, face, and neck should, however, be covered, since exposure of these parts will probably result in burns similar to sunburn, which, while not serious, are painful.

Flux.—It is the experience of a great majority of operators that

flux of any kind is unnecessary in welding. Further, that it is a source of danger, in that there is liability of contaminating the weld. If the work is kept clean by brushing at equal intervals, and ordinary care taken in the operation of the arc, a good weld can be made without flux. If these precautions are lacking, flux will not make a good weld.

Preparation of Welds.—Metal that is clean is much more likely to make a good strong weld. Scale, rust, grease, soot, and any foreign matter will contaminate the weld. Such inclusions necessarily weaken it, or else make it hard. Impurities may also make the metal porous and spongy, owing to the liberation of the gases. Pieces of foreign matter may prevent the molten metal from filling all the parts of the weld and cause cavities. Various methods of cleaning are in use: pickling for small parts, washing with petrol or lye, boiling with lye and sand, sand-blasting, chiselling, scratch-brushing, etc.—the method depending on the local conditions. Preparatory to welding locomotive tubes to the sheets, it is sometimes advantageous to send the locomotive out for a run to burn off the grease, and then clean off the oxide and soot by sand-blasting. Another method is to heat the boiler to normal by steam pressure, and then to clean by sand-blasting or scratch-brushing. Washing with lye will also remove the grease. In welding heavy sections, where it is necessary to deposit several layers of metal on the surface, the preceding layer should always be cleaned before starting the next.

Sections of $\frac{1}{8}$ inch or less in thickness need not be bevelled, but they should be separated about $\frac{1}{8}$ inch. Thicker sections should be bevelled to give a total angle of 60° as well as separated $\frac{1}{8}$ inch. In some special cases angles as low as 40° may be necessary, while as high as 90° may be used; but an average and safe value is 60°. Still heavier sections may be bevelled both sides and the weld made from both sides.

In the latter case a layer should be put on one side, then a layer on the other, to prevent warping; for long seams the edges should be kept about $\frac{1}{8}$ per cent. apart, at the opposite end to which the welding is started; at the end where the weld starts this is to be kept open $\frac{1}{8}$ inch. This takes some of the expansion and contraction of the metal in the sheet. Another method of reducing contraction is to put in short sections at intervals, welding in one layer at a time, starting at the centre and working alternately to each end. Then put a layer on the open sections, and continue in the same way until the weld is complete, the welded section of any layer below or above the joints being broken

as in laying brickwork. Still another method: instead of beginning the weld at the edge of the plate, start it some distance in and weld towards the edge of the plate. Then a second weld is started the same distance ahead of the first section. This method is called back-welding. The length of each section depends on the total length and may vary from 4 to 10 inches. In the welding of complicated shapes, such as flywheels, some castings may require preheating at certain points to produce initial expansion, which will be overcome as the weld cools. In some cases the entire pieces must be preheated; in others, after welding, the whole piece must be annealed. This is done by heating the pieces uniformly, then covering it with sand, asbestos, etc., and allowing it to cool slowly. In welding cracks in plates, forgings, or castings, the crack or fracture should be bevelled entirely through within $\frac{1}{16}$ inch of the bottom.

In boiler work $\frac{1}{2}$-inch holes are sometimes drilled just beyond the crack to prevent further fracture.

Welding with the Metallic Electrode.—The arc should be kept short, not over $\frac{1}{8}$ inch in length. The current should not be greater than that indicated in the table for the electrode. Excessive current burnt or porous metal to be deposited. The arc should be kept constant in length to ensure uniformity in the metal deposited. In welding a seam the electrode should be moved with a zigzag or gyratory motion: the motion must be an advancing one along the seam. The metal will adhere only to the surface of the work actually played on by the arc, so care must be taken to bring the arc in contact with the whole surface to be welded. Be sure that the electrode is connected to the negative terminal. If the polarity is reversed the arc will be more difficult to maintain, the electrode will not be as good as it should be. In starting the arc, the electrode should be just touched to the work, and withdrawn immediately to the required distance. If the electrode is held too long in contact it will not work; in this case the relay, if adjusted properly, will operate opening the circuit, after which the electrode can be knocked loose.

In welding, be sure that the arc plays over the entire surface of the joint. The metal of the work is fused by direct impact of the arc; if the molten metal merely runs ahead of the arc, over the solid metal of the work, it will not result in a weld. The metallic electrode used is generally from 14 to 18 inches long. It may be gripped in the holder, either at one end or in the middle as required by skill of the operator or the nature of the work. The operation of welding overhead is the same as in normal welding. The difficulty largely lies in the holding of the electrode steady in the cramped position

usually required. If the arc length is kept constant the metal will be successfully deposited; practice is required to accomplish this. The appearance of an over weld is sometimes marred by drops of metal projecting, or by uneven thickness of the deposited metal, but this can be overcome by proper manipulation of the electrode. A rest for the arm will sometimes assist the operator to hold the electrode steady.

The Use of the Carbon Electrode.—The holder should grip the electrode from 4 to 5 inches from the end, the electrode for ordinary work to be tapered to a blunt point at the working end. These carbon electrodes are specially made from a superior grade of pure graphite. They are stocked in three sizes—$\frac{3}{8}$ inch, $\frac{1}{2}$ inch, and $\frac{5}{8}$ inch diameter—and 12 to 24 inches long. To deposit metal with the carbon electrode, the arc is struck as above, but it is not held long enough in one place to melt through. A pool of molten metal is established, a melting-rod of metal is fed into the arc melted down in the work. It should all be heated thoroughly to ensure complete union before more metal is added. Since a heavier current can be used with the carbon electrode than with the metallic, faster work can be done in depositing metal. The quality of the weld is not quite so good, however, as when the metallic electrode is used. However, for filling holes in castings, burning up worn spots, etc., the carbon weld is satisfactory and should be used. Owing to the temperature and the large amount of heat liberated when using the carbon electrode, the electrode holder is liable to become very hot, and, under some conditions, melt away at the end. When the holder begins to get hot it should be plunged in the receptacle of water kept conveniently near the operator.

CHAPTER XXXV

SPOT WELDING

SPOT electric welding is the process whereby two pieces of metal are united by heating until they reach a semi-molten or plastic stage, when they can easily be forced to cohere or weld by the application of pressure. The complete cohesion of the heated molecules makes the two pieces of metal practically solid where they are forced together. It is necessary that the area to be welded should, at the start, be brought into more intimate contact than the surrounding areas, in order that the current may be properly localised, and the heat generated in the region where it is needed.

Some of the advantages of spot welding are that the weld is softened or changed in its texture after welding by the application of considerable heat, and for this reason it can be extensively used in the manufacture of stoves or other articles subject to high heat, where even brazing could not stand up. There is no noise in connection with the operation, no dirt, smoke, or wasted heat. The current is only on for a brief period of the time required to heat the two sheets of metal at the point of the weld, and as soon as the welding is completed all expense of current ceases immediately. Owing to the way the metal is forced together, no oxidation can take place on the abutting surfaces; therefore, no welding compound or deoxidiser of any kind is necessary. First the stock must be cold rolled, hot pickled, or sand-blasted to remove all scale or dirt, which acts as an insulator and cuts down the capacity of any spot-welding machine. The welding machine is always ready to make a joint at the will of the operator; yet, as soon as the welding has been completed, the machine is practically dead, and the current expense is stopped until the next operation. The metal is in full view of the operator at all times, and no smoked glasses or goggles are required.

The sheets to be welded must be perfectly flat and in good contact at the surface to be welded, so that no great mechanical pressure is required to flatten down any bulges or dents to bring the two plates of stock into good contact directly under the die-points.

The stock must not surround the lower horn in any way like a cylinder or a rectangular box, as would be the case in welding the seam-side of a can or pipe. These conditions are not to be interpreted as meaning that no spot welding can be done unless they are absolutely followed, but merely to give a basis on which the ratings are calculated. If any of these conditions are violated—which is often necessary, especially the last one—it will still be possible to spot weld, but the capacity of the machine will be cut down. The cut-down of the capacity as outlined (by the stock not surrounding the lower horn) is due to the self-induction effect of the metal, which tends to choke back the main current and in this way cuts down the welding effect at the die-points. This is lost energy, as the amount of current choked back is not used in any way.

The theory of this choking back would be too lengthy to explain in full, but, to give a brief analogy, it might be compared to the back-pressure effect on a petrol engine in a motor-boat, where the exhaust is located under water and the power of the engine is reduced owing to the back-pressure caused by the water pushing against the exhaust gases. This induction effect, so called, is only present in welding iron and steel, no such effect being experienced with brass.

Light gauges of sheet metal can be welded to heavy gauges or solid bars of steel if the light metal is not greater than the rated single sheet capacity of the machine. Soft steel and iron form the best welding materials in sheet metals, although it is possible also to weld sheet iron or steel to malleable iron castings of a good quality. Galvanised iron can also be welded successfully, although it takes a slightly longer time than clear iron and steel stock in order to burn off the zinc coating before the weld can be made. Contrary to common opinion, the metal at the point of the weld is not made susceptible to rust by burning of this zinc, since by some electro-chemical action it has been found that the spots directly under each die-point and also around the point of the weld between the sheets are covered with a thin volume of zinc oxide after the weld has taken place, which acts also as a rust-preventative to a very noticeable degree.

On spot-welded articles used in practice for some time, such as galvanised road culverts, refrigerator-racks and pans, rain gutters, buckets, etc., it has been found that no trace of rust has appeared on the spot welds from their exposure to ordinary conditions. Extra light gauges of galvanised iron below No. 28 B. and S. cannot be successfully welded, owing to the fact that so little of the iron is left

after the zinc has been burnt off that the metal is very apt to burn through and leave a hole through the sheets. Tinned sheet iron or steel makes an ideal metal, giving great strength at the weld, but the stock will be discoloured at this point over the area covered by the die-point in operation. Sheet brass can be welded to brass or steel if it contains not more than 60 per cent. copper. It is not practicable to attempt to weld any bronze or alloy containing a higher percentage of copper than this, as no great strength can be obtained. Another class of work which can be handled to good advantage on a spot-welder, although it is not strictly spot welding, is the construction of wire-work articles.

This mesh welding of two crossed wires is usually done with the same two copper dies as are used for spot welding, except that the dies are usually grooved in order to hold the wire in the desired position to weld. The welding itself is quite as rapid as that of sheet metal, but a jig to hold the wire parts together in the correct position before welding the joint is usually required in order to secure high production. Among common wire-work articles assembled by this method of welding will be found lamp-shade frames, oven racks, dish strainers, waste baskets, etc.

Spot welding requires as part of its equipment a suitable transformer. The essentials for the purpose are:

(1) Very large currents at low voltages, the currents running as high as 50,000 to 75,000 ampères, the voltage 4 to 15.

(2) Different classes or thicknesses of metal having to be welded by the same outfit, it is necessary to provide variation in voltage in order to obtain suitable currents for the different classes of work.

(3) On account of high current it is necessary to have the transformers as near the work as possible to avoid excessive cost of low voltage bus bars.

(4) The fact that the transformer is an integral part of the welding machine, and as such may be subject to very rough usage in factories, blacksmiths' and boiler shops, etc., or may even be exposed to the weather, necessitates particularly rugged construction.

Spot welding is the method of joining metal sheets together at any desired point by a spot, the size of a rivet, without punching holes or using rivets. It is done electrically by fusing or melting the metal at the point desired, at the same instant applying sufficient pressure to force the particles of molten metal together. The theory is as simple as its application. It is a well-known principle that a poor conductor of electricity will offer so much resistance to the flow of the current that it will heat, the degree of heat depending on the

amount of current and the resistance of the conductor. Copper conductors carry the current with very little resistance. Place a piece of iron in the circuit: it is not so good a conductor as the copper, and will heat. If the volume of the current is large, and the iron conductor much smaller in diameter than copper, the iron will

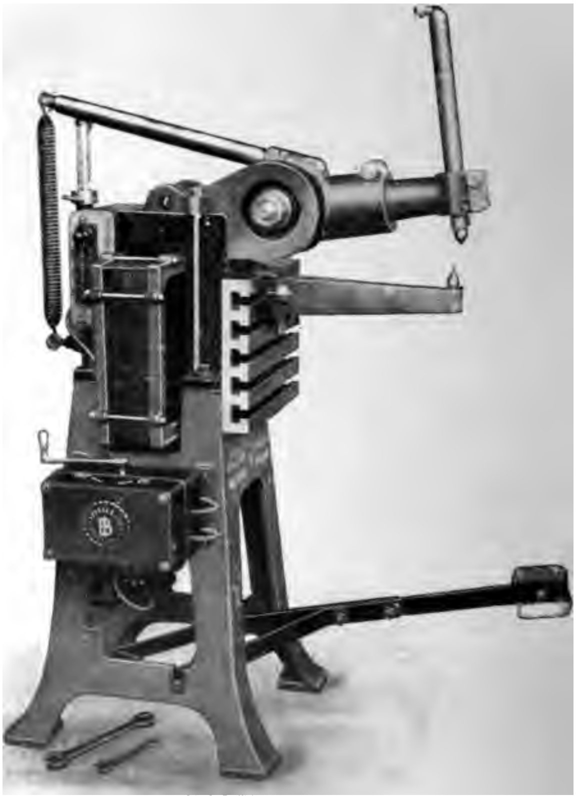

FIG. 112.– PRESCOT SPOT WELDER.

quickly become hot enough to melt. An incandescent lamp offers a good illustration of this principle: the copper wires leading to the lamp are good conductors and remain cool; the carbon filament, being a poor conductor, becomes white-hot, and reaches a state of incandescence.

Instruction for Working the Machine.

Set the regular handle to the extreme left-hand side, No. 1, and the double-pole, double-throw switch to the left. Place the work between the copper die-points and close the dies on the work.

FIG. 113.—THIS IS A SPECIALLY GOOD SAMPLE: FIRST, THREE FLAT BARS TO CORRUGATED SHEET; SECOND, A FLAT PLATE WELDED TO THE FLAT BARS AND PLATE; FOURTH, BENT FLAT BARS WELDED TO CORRUGATED SHEET, FLAT BARS, PLATE, THROUGH ALL PIECES.

This will force the stock together. The current is turned on with the switch. If the stock does not heat rapidly enough, turn the regulator-handle to the right, or No. 2. If not enough is obtained at this point, keep on until the point is reached; if enough heat is

FIG. 114.—ONE PIECE OF ANGLE IRON TO FLAT PLATE. TWO SPOTS.

not obtained, throw the double-pole switch to the right, and the lever handle to No. 1. The maximum current is obtained when the regulator is at the right.

There is absolutely no danger of getting a shock on the machine between the upper and lower dies, as can readily be proved by plac-

ing the fingers through from the upper to the contact points and turning on the currents.

The voltage is so low that it is impossible to feel anything. Do not touch the wires leading from the transformer or dynamo to the machine without first opening the switch on the wall. There is no occasion for the operator to touch these wires in any way after the machine has been connected up.

Figs. 113, 114, and 115 are samples of spot welding.

There is a limit to the thickness of sheet metal which it is commercially practicable to spot weld, owing to two causes:

First, the fact that the copper rods which conduct the electric current can only carry a certain quantity of current without excessive heating. When sufficient current is carried over these copper rods or die-points to bring the heavy bodies of metal up to the weld-

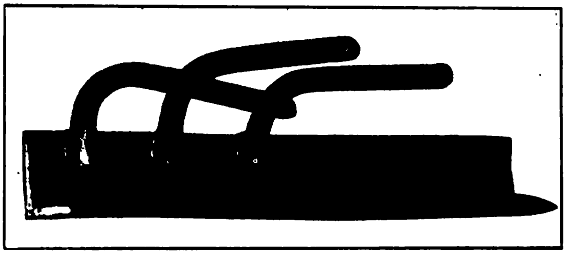

FIG. 115.—THREE PIECES OF ROUND IRON WELDED TO AN ANGLE IRON. GOOD TEST.

ing temperature, the copper rods will become hot; then they soften, and the points will wear away quite rapidly.

Secondly, it being necessary to have two pieces of sheet steel touching each other at the point where the weld is made, with very heavy stock a slight kink or buckling of the metal will prevent the flat surfaces from touching each other and making good contact. Light gauges of sheet steel can be welded to heavy gauges or to solid bars of steel. It is not possible to weld two pieces of cast iron, owing to the crystalline structure of the metal. Sheet steel can be welded to cast iron, but can easily be pulled apart. The sheet tears out small particles of cast iron. Galvanised iron can be welded, although it will burn off the zinc somewhat where the weld is made. The author does not advise the welding of light galvanised iron above 24 gauge, as there is no body of metal to work on. By the time the weld is done the zinc is burnt off and there is nothing left. Sheet brass can be welded to sheet brass or sheet steel. There is a little

knack in welding work of this kind, and it may take a bit of experimenting to get the right heat and pressure.

Some grades of sheet aluminium can be spot welded, although it will leave a slightly roughened surface where the die-points come together. It is more difficult to weld sheet copper to sheet copper, as this metal is such a good conductor of the electric current that there is practically no resistance offered by the metal. Rivets of any size can be heated after the rivet has been set in the rivet-hole, and headed and pressed in place at one operation by use of the welder. This process can be used to advantage in many cases. Heat has no effect on the electric weld. For this reason the process is largely used by stove manufacturers in making sheet-steel ranges, and for similar work.

To facilitate the welding of awkwardly shaped articles the bottom stake may be swivelled and raised or lowered. With such a combination it is practicable so to arrange the stakes that the most awkwardly shaped articles can be handled. The welder is foot-operated, and no skilled labour is required. Foot pressure on the pedal brings down the top electrode towards the bottom electrode, pinching between them the articles to be welded, which are held there by the operator. The same downward movement of the pedal switches on the welding current. After welding temperature is reached—judged by the colour—further pressure on the pedal trips the switch and applies pressure to force the heated metal into welding. The pedal is made reversible, so that the welder may be operated by either right or left foot. The tips are made of copper and are water-cooled, with a constant flow of water. The system of cooling is so efficient that the tips may be touched by hand immediately after welding. Usually the tips last for a few weeks' constant use. They are easily and cheaply replaced.

Operating Instructions.—Select the pieces to be united, range them together in the required position, just as they will be when welded, and clamp them thus between the electrode tips. This is done by holding the pieces on the bottom electrode until the top electrode has been brought down by depressing the foot-lever. Directly the pieces are clamped between the electrodes, they become white-hot at the points where the electrode tips make contact; and the pressure between the surfaces, maintained by the foot-pedal, forces the metal to unite and forms a weld. The metal should be as free as possible from rust, scale, dirt, or other foreign matter likely to hinder the passage of the welding current. No preparation is necessary unless the metal is very dirty, in which case it will be economical

to clean it, since less current will be required. The time taken to weld varies from a fraction of a second to perhaps one second. No definite rule can be given that will decide all cases. It depends on the thickness of the metal, its freedom from dirt, the position of the plug in the plug-box, and the diameter of the spot weld made. A few hours' experimenting is generally sufficient to teach the average operator. The plug should be in No. 1 hole when welding the thickest material, in No. 4 for the thinnest. The shape of the electrode tip decides the diameter of the spot. If a small spot be required, the tips must be reduced at the tip; if a larger spot, the tips must be flattened.

Adjustments, Tips.—The electrode tips will require to be filed from time to time, to remove any metal which may adhere to them. Each tip is quite easily removable after loosening with a spanner. Care should be taken not to turn the tip completely round, as one would a nut. Just move it from left to right a few times, when it will be loosened and may easily be removed.

Three types of electrode tips are made:

(1) Concentric—that is, with welding point exactly in the middle of the electrode.

(2) Eccentric—that is, the welding point a little out of centre.

(3) Flat—that is, no welding point at all.

The concentric type is most often used, but it demands a maximum amount of clearance around the weld. For welding in corners and places where there is little room, the eccentric is used. The flat type may be used with either a concentric or eccentric tip, but it is only used when it is desired to avoid, on one side, the little indentation made by the pointed electrodes. All these tips are interchangeable, suitable for either top or bottom stakes.

Pressure while Welding.—One of the most important points to remember is the necessity of having a fair pressure between the surfaces to be welded before the current is switched on by closing the switch at the back of the welder. This can easily be arranged for by moving the top or bridge of the switch up and down the rod on which it is mounted, adjusting so that the electrode tips are forced well together before the switch closes. Care must be taken to see that the electrode tips are directly in line when touching. If one is a little to the side of the other, the weld is likely to be burnt. Directly the article to be welded is clamped between the electrodes, the secondary circuit is closed, but no current flows until sufficient pressure has been set up by the foot-pedal to close the primary switch at the back of the welder. Closing the secondary circuit before the

primary ensures a steady flow of current through the point of the weld, free from sparking.

Switch.—This is fitted at the back of the welder and should be inspected from time to time to ensure the points of contact being kept clean.

Hinge.—To permit the top arm to move down easily when the foot-pedal is depressed, while yet maintaining good electrical contact, it is carried in a special hinge. The arm rocks up and down on ball-bearings, and electrical contact is ensured by two discs, which are a sliding fit in the secondary casting, and are pressed up against the top arm by the springs under the nut-washers on each side. These nuts may require tightening from time to time, so as to keep the contact discs in close contact with the top arm. Great care must be taken not to make them too tight, or excessive friction will be set up and the faces will be scored. No lubricant must be used. Should the faces at any time become scored, take the hinge apart, smooth the faces, and polish with metal polish. The ball-bearings require no attention.

CHAPTER XXXVI

ELECTRIC BUTT WELDING

ELECTRIC butt welding is a process wherein two pieces of metal are united by the cohesion of their molecules, induced by the application of pressure when they are in a plastic or molten stage through being heated by some process. In the process of electric welding the heat is induced by passing a large volume of electric current at a low pressure through the two surfaces of the pieces to be welded, the heating effect in any electrical circuit being evoked by the resistance of the metal to the flow of the current. When the point between the abutting ends, which has the highest resistance in the circuit and therefore the highest heat, has reached the proper welding temperature, the current is turned off and the pressure applied mechanically to force the molten ends together, thereby producing a weld.

Butt-welding machines are designed for the manufacturer who has a large quantity of this kind of work to do, where there are many pieces of one kind to weld. They are not intended to replace the blacksmith for general repair work where there are a few pieces of various sizes to be welded. It is purely a production proposition for a volume of work with a minimum of cost.

In butt welding the two pieces of metal are placed in the clamping jaws of the machine with a proportion of the ends extending beyond the jaws. The electric current is turned on by means of a switch, and the abutting ends of the metal instantly begin to heat. The operator quickly learns to judge by observation when the welding temperature is reached. When he sees that the metal is hot enough, he applies the pressure and forces the two metal ends of the pieces into each other, at the same time turning off the current, and the weld is made. The metal is in full view of the operator all the time, instead of being hidden by the coal and flame in a forge fire. No smoked glasses or goggles are needed any more than they are by the blacksmith. There is no scarfing to be done, and owing to the way the metal is forced together, there is no oxidation such as there would be in the open fire. Consequently, no welding compound is necessary. In a forge fire a thin film of oxide forms on the metal,

which must be removed by a welding compound from the two surfaces to be joined before a good weld can be made.

With electric welds the heat is first developed in the centre of the metal. In consequence, it is welded there as perfectly as the surface. When welding electrically, little energy or heat is wasted in heating more of the material on either side of the weld. The operator has complete control of the electric current by means of his current regulator and switch. He can quickly obtain any heat desired, from a dull red to the melting-point of the metal. The instant the weld is made the expense for current stops. Owing to the low voltage employed across the work itself there is not the slightest danger of injury to the operator. He cannot even feel the current if he should come in contact with it across the dies. The parts to be welded can be kept in fairly close alignment by the clamping of the jaws, which can be given almost any shape desired to hold the work. The current has no effect on the welded metal, its action being to heat the metal. The copper clamping dies are good conductors, and a bar of iron, being comparatively a poor conductor, when placed between the clamping dies of the welder becomes heated in attempting to carry the large volume of current. The degree of heat depending upon the amount of current and resistance of the conductor when the ends of the two pieces of bar are brought together, this is the point of the greatest resistance in the electric circuit, and the abutting ends heat most rapidly.

Production will depend largely on the operator, the size and shape of the piece to be welded, and the kind of machine used. There is a wide range in the time between the heavy pieces and the light pieces which can be handled rapidly and easily. Some of the smaller machines deal with several thousands of pieces a day, and to get the maximum output the best machines should be adopted. The welding machine can be used on one phase of a three-phase system, but cannot be connected to more than one phase of a three-phase circuit. Direct current cannot be used, because there is no way of reducing the voltage without interposing resistance, which uses up the power. The voltage used at the weld is from 1 to 15, depending on the size of the welding machine. To obtain this low voltage or pressure, a special transformer inside the machine reduces the power line voltage down to the range. It is like reducing steam pressure from 100 to 10 pounds.

The welding transformer which produces the heavy current across the work is supported with the frame. Single-phase alternating current is taken from a generator, or power circuit, and is stepped

down by the transformer to a low potential of from 1 to 15 volts. The secondary winding of the transformer is connected to the platens, and the current travels through the platens, clamps, and metals to be welded, thereby completing an electric circuit. Since the current value rises as the potential falls in the secondary circuit, and since also the heating effect across the work is directly proportioned to the current value, it is easily seen why a transformer is necessary to produce a heavy current by lowering the time potential. Owing to the intermittent character of the load, there is no standard rating for welder transformers. Different makers will give entirely different ratings for their machines, and not infrequently make misleading statements regarding the current used. Regardless of the rating in k.w. capacity, there can be very little difference in the actual amount of current consumed unless an exceptionally bad transformer design is used. To heat a given size stock to the welding temperature in a given time requires approximately an invariable amount of current.

The following illustration shows a machine for welding tool steel. In any tool welding there are different kinds of welds to be made, which require different classes of dies and two different types of machines. We will first deal with the class of work which comes under reamers, milling and key-way cutters with taper shanks, and other similar make-up. The high speed and the carbon steel pieces should be prepared to secure the best results on a production basis. When making this style of tool the dies should be specially prepared to do the work. Since the high-speed steel has a higher resistance than the carbon steel it has a great tendency to reach the plastic stage of heat sooner than the latter. For this reason it should have a shorter projection beyond the dies to secure still greater cooling effect and to retard its heating as much as possible.

Thorough tests have been made on the strength of electrically welded bars which prove that they are almost as strong at the welded joint as at any other cross-section of the metal. When welding in a forge, the outer surface is heated first, and the inner part does not very often reach welding heat, the result being an imperfect weld. The only preparation of the stock necessary for this process is that, when it is rusty or covered with blue scale, the rust and scale should be removed sufficiently to give good contact of clean metal at the gripping dies, as both scale and rust are poor conductors.

The butt-welding process is applicable to the welding of pieces having practically the same cross-section at the joint. A very few seconds after the current is turned on in the welder, the metal reaches

a white heat, and is in a partially molten state. By means of heavy pressure the ends of the metal are forced into each other in this semi-

Fig. 116.—Butt-Welding Tool Steel to Mild Steel Bars.

fluid condition, extruding all burnt metal, thus making a homogeneous mass and a perfect weld. A projection or fin will be raised where the ends come together, by the squeezing out of the burnt metal,

which may be very slight on an "upset," or quite a fin may be raised in a flash weld. Both are shown below.

Butt Electric Welding Process.—The parts to be welded are brought into contact under pressure and then a current of high amperage under low voltage is passed from one part through the joint to the other part. Because of the high resistance at the contact areas, the metal at the joint is quickly brought to a welding heat, when the plasticity of the metal allows the pressure to cause movements of the two parts towards each other. Under the combined temperature and pressure the parts are welded, much as welding is done under the blacksmith's hammer—perhaps, above all, in that the heating and welding operations are performed practically at the same time and almost instantaneously. As soon as the welding heat is reached the welding is immediately effected. In the lighter kind of work the rapidity with which this heat is attained is

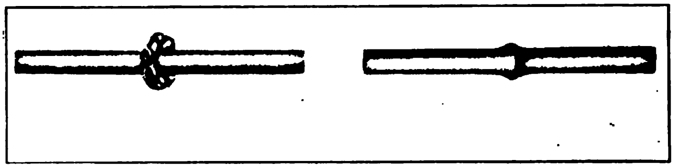

FIG. 117.—BUTT WELD. RIGHT, FLASH WELD; LEFT, UPSET WELD.

quite remarkable. Although the process is not applicable to every form of welding, yet the sphere of its utility is very wide, and the quality of the work effected by it is unquestionably good. It is necessary for its effective operation to have at command heavy flows of current, but, on the other hand, the voltage is very low. In some cases as low an electromotive force as half a volt is all that is required. In actual practice from 4 to 6 volts is about the highest pressure worked with. The temperature of the metal to be welded is raised simply by a very heavy current flowing through a restricted area. The British Insulated and Helsby Cables, Ltd., make a large variety of these machines for electric welding on the resistance system. The electric arrangements involved in all machines are fundamentally the same as those employed in all systems of resistance welding—that is to say, each machine embodies a transformer, wound so as to perform the particular work desired under the conditions of voltage and periodicity of the supply current available. The secondary coil of the transformer consists of a single convolution, having a large cross-section of copper, which terminates ex-

ternally in the two electrodes, which are of various forms. The pieces to be welded are brought between these two electrodes, thus completing the electrical circuit of the secondary coil, so that when the primary circuit is closed a heavy current flows in the former, as the resistance to the flow of that current is practically all centred in the surfaces in contact. Since the ohmic resistance of the secondary

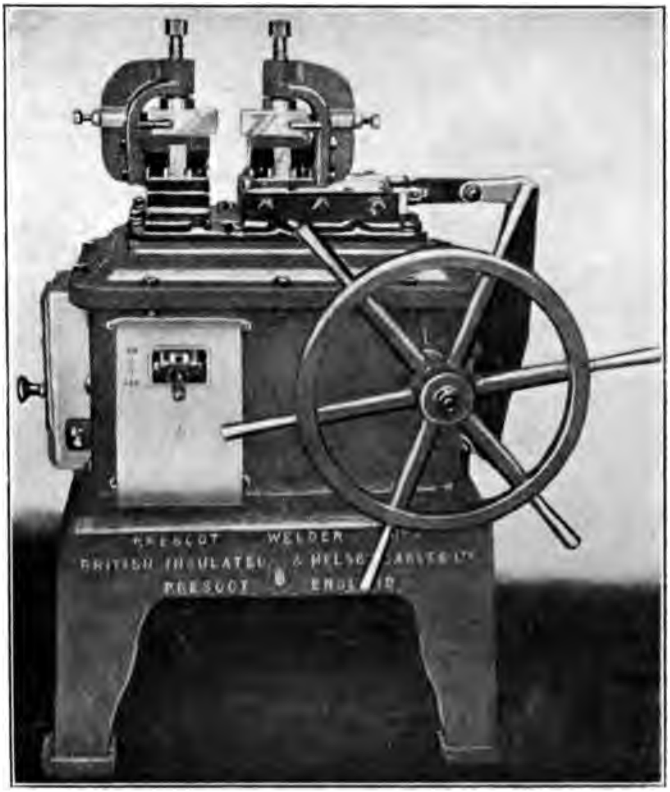

FIG. 118.—BUTT WELDER FOR TOOL STEEL AND OTHER WORK.

winding is comparatively negligible, great heat is developed between the electrodes, and the material between them is quickly brought up to a welding temperature.

Attention may be drawn to the various types of butt-welding machines to suit different purposes: (1) Welders for wire with automatic upsetting gear for uniform section iron, steel, or non-ferrous

metals; (2) welders for manufacturing purposes with hand or automatic upsetting gear for regular sections; (3) chain welders.

Wire welders is the term which applies to the machine in No. 1, some capable of welding 0·024 diameter. Larger machines of this type are able to weld material up to 1 inch square. The machines in the second category are used for such manufacturing purposes, amongst a host of others, as welding pipe refrigerator-coils, milk-can rings, perambulator rings, printers' chases, fittings to casement

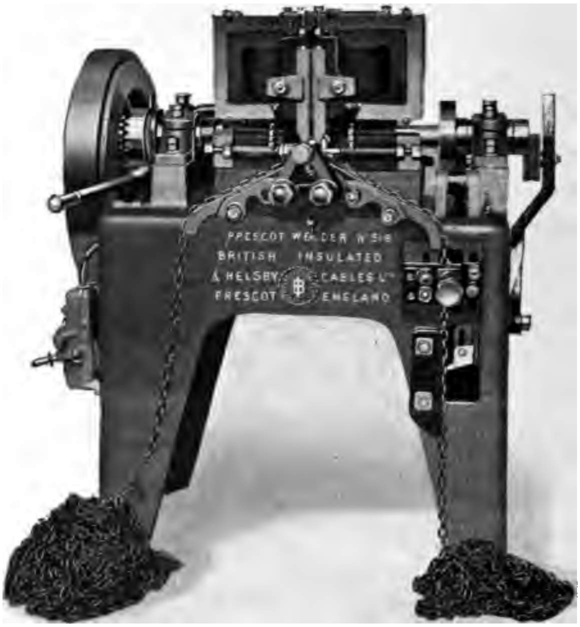

FIG. 119.—BUTT WELDER MAKING CHAINS AUTOMATICALLY.

frames, carriage and coach work parts, trellis work, coupling links, brake rigging, travelling-bag frames, low-grade shanks on high-speed tools, drills, taps, etc.

The chain welders form a class by themselves, though the general principles involved are very much the same as those of other machines. The manufacture is carried out from coils of wire by two machines, the first of which bends the links and threads them into a chain, whilst the second forms the welds. Although the first machine is not shown in this book, it is necessary to describe it, since the

complete process cannot be properly understood without it. Three machines are made which deal with wires from $\frac{3}{32}$ to $\frac{7}{16}$ inch. The smallest machine turns out 50 to 60 links per minute and takes 1 to $2\frac{1}{2}$ horse-power to drive it. The middle size turns out 40 to 50 per minute, and requires 2 to 4 horse-power to drive it. The large one makes from 20 to 30 links per minute, and the horse-power needed is 3 to 7. The minimum proportions of the links made on these machines are—length 5 diameters and width 3 diameters of wire.

General Information.—The material to be welded should be ground or filed flat and square at the abutting ends, otherwise accurate results cannot be obtained. The wires to be joined are each gripped in a vice and the two ends projecting equally; one of the vices is movable and the other fixed. While the machine is being set up a spring pressure is taken up by a pawl engaging with a rack. While welding, the pawl is disengaged, and this pressure is transmitted to the joint. As long as the wires are cold the side remains stationary, but as soon as the current is sent through they soften and give way: the weld is jumped as soon as the required temperature is reached, and simultaneously the current is cut off, nothing further taking place.

The illustration on the opposite page is of a chain welder, which has been described previously.

CHAPTER XXXVII

ELECTRIC SEAM WELDING

SEAM welding is a process of joining two overlapping edges of sheet metal for their entire length by perfect cohesion of the molecules of the material itself, without the application of any solder or spelter between the edges of the joint. In the process of seam welding the heat is produced by passing a large volume of electric current across the joint of the edges to be welded by the employment of a copper roller on one side of the joint, a copper track or horn underneath. In any electrical path, wherever high resistance is interposed, heating will result. The higher the resistance to the current the greater will be the heating effect. In seam-welding machines, since the copper rollers and horn are good conductors, the joint between the edges of the metal to be welded is the point of highest resistance, and it is evident that the greatest heating effect will be at this point. As the roller passes over the joint, heating the stock to a plastic state beneath it, pressure is simultaneously applied by the springs on the roller to force the edges together as fast as they are heated.

Since 20-gauge metal and lighter heats very readily, the pressure and the heating can be effected at the same instant of contact by the roller. It is possible to weld as fast as 6 inches a second. The only preparation necessary for seam welding is that the stock must be absolutely clean—that is, free from any traces of rust, scale, grease, or dirt—if a tight, neat joint is desired. If it is not necessary for the joint to be tight, the stock need not be so clean, although heavy rust and scale will prevent the carriage of the full current, the heating will be affected, and the weld will not be so good.

In welding sheet brass from 22- to 30-gauge, to secure a perfect joint the metal should be carefully pickled and washed to remove all traces of grease and tarnish, which tend to prevent the passage of the current across the joint of the edges. The metal should be welded soon after pickling, as, no matter how carefully it may have been washed, oxidation is always sure to start very shortly after the brass has been removed from the pickling acid.

Steel to be successfully seam welded should not have a carbon

content of over 0·15 per cent. A higher carbon steel than this has a tendency to crystallise at the point of the weld, owing to the rapid cooling of the welded portion from the surrounding cold metal. After welding, the joint will be found to be about one-third thicker than the thickness of the metal. It is possible by applying more pressure to reduce this finished thickness, but it wears more on the copper roller to do so. In seam welding brass, a soft, annealed metal should be used, for, although hard rolled brass can be welded, it forces the two edges together very much, and the finished joint under these conditions is almost twice the original thickness. With a soft, annealed

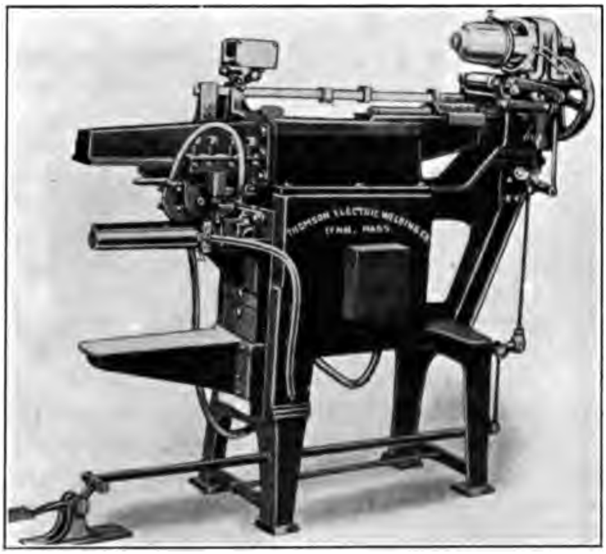

FIG. 120.—ELECTRIC SEAM-WELDING MACHINE.

brass the finished joint will not be over a third greater than the single metal thickness, and by applying sufficient pressure it can be reduced to not over 10 per cent. thicker.

The principal advantage of the process of seam welding in brass and other non-ferrous metals is that no spelter or flux is required, nor is there any volatilisation of the zinc, the metal itself furnishing its own cohesive properties. This allows of great speed in production. The great ability of a seam welder to secure the highest production lies, not only in its welding qualities, but in the adaptation to the welding machine of a suitable jig. The jig holds the work properly,

and also enables the operator to place the piece in it and remove the same in the shortest possible time, since the welding itself is very fast compared with any other method of making a continuous joint.

Fig. 120 is a photograph of a seam-welding machine. The operation is very simple, once the machine is set up, for any given piece of work for which a special jig has been built. After placing the piece in the jig and locking it there securely, the operator depresses the foot-pedal, which throws in a clutch and starts the copper roller across the work. By the proper setting of adjustable control-stops on the control rod on the top of the machine, the current is automatically turned on as the rollers enter on to the overlapping edges of the piece to be welded, and is automatically turned off when the roller reaches the end of the stroke. Another stop reverses the travel of the roller, bringing it back to its starting position. The control stop may be adjusted to turn the current on and off at any point along the roller, for doing a seam shorter than the maximum of the welding machine. The roller stroke may also be shortened so that a complete cycle of operations will be accomplished in the shortest space of time on seams shorter than the maximum seam capacity of the machine. In order to keep the copper roller from overheating in action, water is introduced through its bronze bearings on each side. This same water circulation passes also through the under copper horn or madrel, then through the cast copper secondary of the transformer, so that the machine can be operated continually—twenty-four hours a day if desired—without overheating.

Most seam-welding machines are equipped with variable-speed motors in order to give a range of variation in roller travel speed, which is necessary for different lengths and thicknesses of stock. They are also equipped with a current regulator to give fifty different voltages at the copper roller.

To effect good sliding contact with copper track, several springs are employed on each side of this slide, which carries the copper rollers. The lower horn is bolted directly to the lower terminal of the transformer secondary. The particular design in each case will depend upon the size and the nature of the work.

CHAPTER XXXVIII

EYE-PROTECTION IN IRON WELDING OPERATIONS

IN welding operations three kinds of radiations must be guarded against, one or all of which may be present to an injurious degree. The problem is to provide a perfectly safe filter that will permit of the greatest degree of visibility, and at the same time will exclude the infra-red, or heat, rays and the ultra-violet rays. Ordinary glass lenses of special colours or combinations of colours are required. I show the spectra of a number of commercially available glasses and combinations of these glasses, and a glance at these charts will show what arrangement of filter will provide the best protection against the radiations of the welding arc.

Radiation from an intensely heated solid or vapour may be divided under the headings: (1) Invisible infra-red rays; (2) visible light rays; (3) invisible ultra-violet rays.

There is no clear line of demarcation between these divisions, as they melt gradually one into the other like the colours of the visible spectrum. When the heated matter is solid, such as the filament of an incandescent lamp, the visible spectrum is usually continuous—that is, without lines or bands, but when it is in the form of gas or vapour, as in the iron arc used for welding operations, the spectrum is divided up into bands, or is crossed by lines which are characteristic of the element heated.

In Fig. 121 *A* shows the continuous spectrum made by the light of a Mazda lamp operated at normal voltage, and is the line of spectrum made by a disruptive arc between iron terminals.

If *A* and *B* (Fig. 121) were coloured they would show all the hues of the prismatic spectrum from red at the left to violet at the right, as roughly indicated by the vertical dividing lines. The iron spectrum *B* falls a little short of the continuous spectrum *A* in the red, but it is more intense than *A* in the visible blue and violet, and it also extends farther into the ultra-violet. The spectrum *B* contains many lines besides those pertaining to iron, principally those of carbon, nitrogen, and oxygen, these elements being unavoidable components of the electric spark discharge. Inspection of *A* and *B*, however, will serve to indicate the extent and general characteristics

of the visible light that is emitted by highly treated iron vapour in the process of arc welding.

The radiations under the foregoing three headings, although of

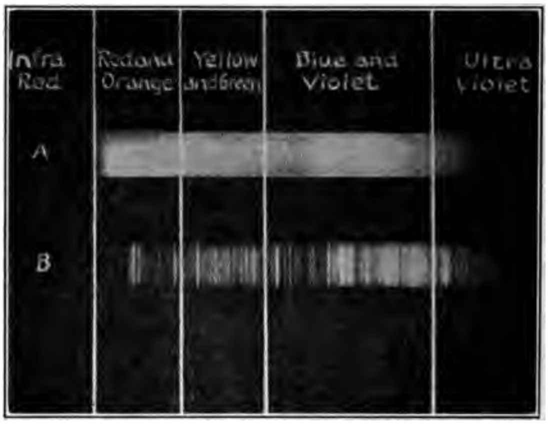

FIG. 121.—SPECTRUM OF A MAZDA LAMP; SPECTRUM OF IRON ARC.

common origin, produce very diverse effects upon our senses. Thus, the infra-red rays produce the sensation of heat when they fall on our unprotected skin, and, therefore, special glasses are required to protect the operator from their harmful effects.

FIG. 122.—PFUND GOLD GLASS GOGGLES.

For welding with acetylene and for light electric welding it may be necessary only to protect the eyes with goggles fitted with suitable coloured glasses. Fig. 122 shows a good form of goggles

which are fitted with lenses of pfund gold glass to which reference will be made later.

Fig. 124 illustrates the front and back views of a hand shield, which is made of light wood and has a safety coloured glass window in the centre. This device is used for medium weight electric welding work which can be done with one hand, and it serves the double purpose of protecting the eyes of the operator and shielding his face from the heat rays and the ultra-violet radiation which would otherwise cause a severe sunburn effect.

For heavy electric welding which requires the use of both hands it is common practice for the operator to protect his eyes and neck

FIG. 123.—A POPULAR FORM OF HELMET WITH CIRCULAR WINDOW.

with a helmet fitted with a round or triangular window of safety glass. These helmets are usually made of some strong, light material such as vulcanised fibre and are designed so that they can be slipped on and off easily, the weight resting upon the shoulders of the operator. A useful form of helmet with a circular window is shown in Fig. 123. Front and back views of another form of helmet are seen in Fig. 125.

It therefore naturally follows that a much clearer definition of an object is obtained by combination of yellow-green light than by red alone, or especially by blue or violet light alone. The eye is also more sensitive to the yellow and green rays than to the red and

blue rays, or, in other words, yellow-green light has the highest luminous efficiency. This may easily be verified by looking at a sunlit landscape or fleecy clouds in a blue sky through plates of different coloured glass. A glass of a light amber colour, slightly tinted with green, will clearly bring out details that are hardly observable without the glass, and which can be obscured entirely by a blue or violet glass. It is therefore obvious that, in order to obtain the clearest definition or visibility with the least amount of glare, the selection of the colour tint in safety glasses should properly be decided by an expert, but the depth of tint, or, in other words, the amount of obscuration, may be best determined by the operator himself owing to the individual difference in visual acuity which will permit one man to see clearly through a glass that would be too dark for another man.

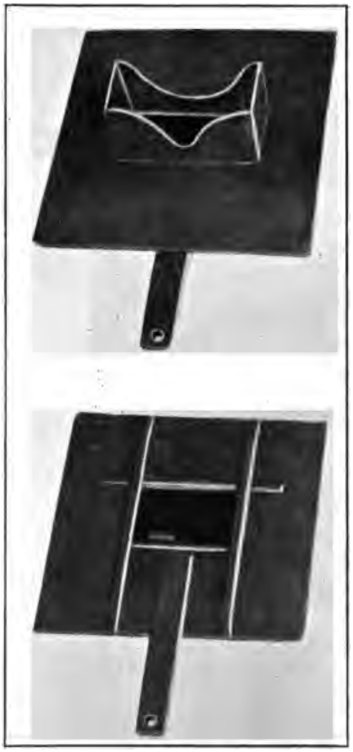

FIG. 124.—WELDER'S HAND SHIELD.

A proper selection of colour tints can be assisted by spectroscopic examination, and the various spectra shown in the accompanying photographs are presented with this purpose in view.

Fig. 126 shows different spectra made by transmitting the light of a Mazda lamp operated at normal voltage: *C*, through clear colourless glass; *D*, through ruby glass.

The screen of clear colourless glass in *C* naturally transmits all the colours of the visible spectrum, extending from the extreme red to the extreme violet and penetrating slightly into the ultra-violet, because the latter rays, although they are not visible to the eye, are highly actinic, and therefore affect the photographic plate. In this case, however, we only see just the beginning of the ultra-violet spectrum, as the glass plate and the glass prism of the spectroscope absorb and cut off all but a few of the least refrangible ultra-violet rays.

The ruby glass, used as a screen in *D*, transmits all the red and orange rays with a trace of the yellow, but it absorbs and cuts out all other colours.

The glass used in spectrum *E* is made by the Pittsburg Glass Company (Pa.), and is termed "Belgian pot-yellow" glass. It cuts off a little of the red, transmits all the orange and yellow rays and a portion of the green, but cuts out all the blue and violet.

The emerald-green glass marked *F* is seen to transmit all the yellow and green, with a considerable portion of the red and orange and also of the blue.

The spectrum made through the cobalt-blue glass marked *G*, shows the transmission of a band of red and a band of yellow-

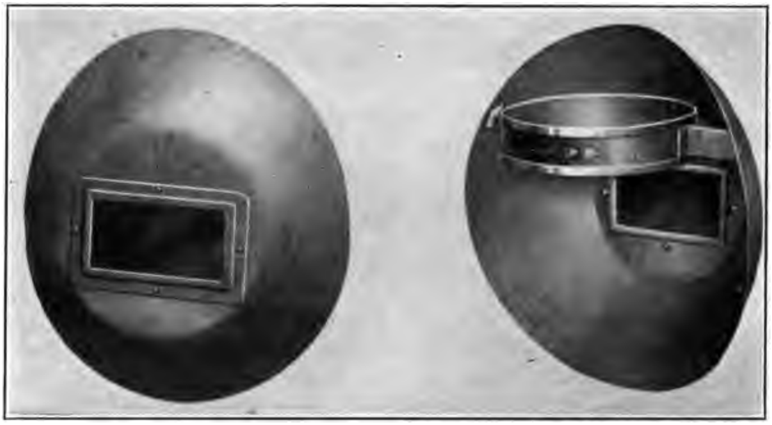

Fig. 125.—Front and Back Views of Thin Sheet Aluminium Helmet Supported by a Head Band and Fitted with Rectangular Opening.

green, but it is chiefly marked by its strong transmission of the blue and violet, and especially in its being a little more transparent to the ultra-violet than the colourless glass *A*.

These five glasses are samples taken from actual service, but on account of the fact that all coloured glasses are subject to considerable variation in tint and depth of colour, caused by differences in chemical composition, heat treatment, etc., the spectra shown in Fig. 126 can be considered as only generally representative; samples of blue glass, for example, have been tested and found to absorb very much more of the red, yellow, and green than the sample shown in *G*.

In *H* is seen a representative spectrum taken through a noviweld

glass (No. 6 grade), which presents an excellent colour combination to secure clear definition with the least amount of glare.

It is possible to produce satisfactory colour tints for welders' glasses by combining plates of different coloured glass. The results of some of these combinations are shown in the spectra of Fig. 127, which were made with the same source of light as those of Fig. 126.

In Fig. 127 *J* shows the full spectrum through clear colourless glass for comparison, the same as *C* in Fig. 126.

In *K* we see the effect of combining yellow and blue glass (*E* and *G* of Fig. 126), which combination makes a fair resemblance to noviweld, and is giving satisfactory service in certain work where the cost of noviweld prohibits its use. The tint of this combination

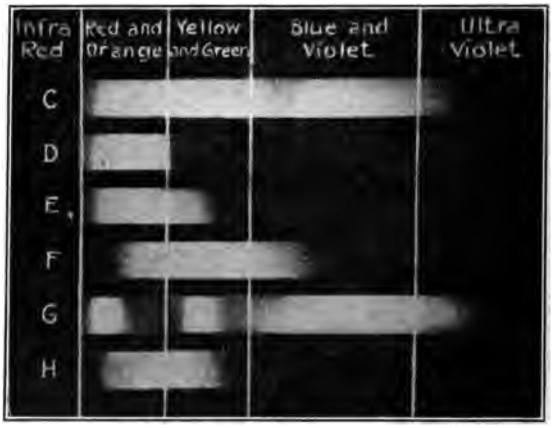

FIG. 126.—SUNDRY SPECTRA 6.
E, Through "Belgian pot-yellow glass"; *F*, through emerald-green glass; *G*, through cobalt-blue glass; *H*, through No. 6 "noviweld" glass.

is inclined rather too much to the red, and is somewhat weak in the yellow-green, but these defects could be largely overcome by a careful selection of the plates.

The spectrum *L* in Fig. 127 results from a combination of ruby and emerald-green glass (*D* and *F* in Fig. 126), which has been found satisfactory for certain work and is now used extensively.

The result of combining ruby and blue (*D* and *G* in Fig. 126) is shown by *M* in Fig. 127. It was formerly used to some extent, but is now almost universally superseded by *L*.

The spectrum *N* was taken through a single plate of noviweld (No. 5 grade), which presents the elements of an ideal colour com-

bination, being weak in the red while transmitting all the orange, yellow, and green, but totally excluding the blue and violet.

The spectrum P was taken through a piece of amber mica having a little darker tint than No. 5 noviweld. Its close resemblance to the noviweld spectrum is remarkable, and if it were possible to procure a clear dark amber mica in pieces large enough to be serviceable, this material, when protected from mechanical injury between plates of plain clear glass, would closely rival the noviweld. Clear dark amber mica of uniform tint and even cleavage is, however, very difficult to procure, for which reason there is no probability that it will ever supersede glass for protective purposes.

In selecting coloured glasses, great care should be taken to dis-

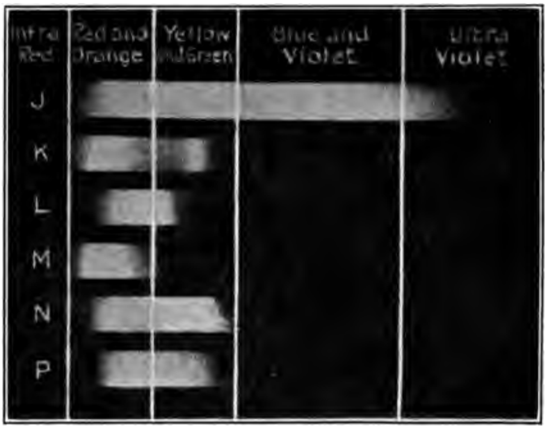

FIG. 127.—SUNDRY SPECTRA 7.

card all samples that show streaks or spots, as these defects are liable to produce eye-strain. The glass should be uniform in colour and thickness throughout, and the coloured plates should be protected from outside injury by a thin piece of clear glass that can easily be renewed.

Having considered briefly the best means for toning down the glaring and flickering visible light produced in the welding process, we may now direct some attention to the infra-red and the ultra-violet rays, which always accompany the visible glare.

When the invisible infra-red rays encounter any material which they cannot penetrate or which is opaque to them, they are absorbed and changed into heat. Hence they are frequently termed heat rays. It is therefore very necessary to guard the eyes from these rays, and,

although they are absorbed to a certain extent by ordinary coloured glass, this is not sufficient protection against any intense source. There are, however, several kinds of glass which, although fairly transparent to visible light, are wonderfully efficient in absorbing heat.

Corning glass G 124 J is one of those which, while it transmits 60 to 70 per cent. visible light, cuts off about 90 per cent. of the heat rays. The colour of this glass is pale green. The author has a pair of goggles fitted with plain lenses of this glass and has found them invaluable when operating on high-temperature work. There are, also, gold-fitted glasses which are superlatively efficient in absorbing and reflecting the infra-red heat rays. A sample of the "pfund gold glass" previously referred to was found by careful test to transmit only 0·8 per cent. of the heat rays generated by a 200-watt gas-filled tungsten lamp operated at normal voltage, the temperature of the tungsten spirals being estimated at 2,400° C. This glass transmits light of a green colour and is much darker than the corning G 124 J, so it probably passes not more than 20 per cent. of the visible rays. The noviweld glasses, especially those of dark tints, are also very efficient shields against the infra-red rays. The effects of even low-power heat rays, when generated in close proximity to the eyes for a considerable time, are often serious, as is evidenced by the fact that glass-blowers who use their unprotected eyes near to hot gas flames of weak luminous intensity, are frequently afflicted with cataract, which might be positively avoided by wearing spectacles made with plain lenses of the G 124 J glass or its equivalent.

Fig. 128.—Goggles: 47 H, 48 H, 49 H.

Table I. indicates roughly the percentage of heat rays transmitted by various coloured glasses of given thickness. The source of heat used was a 200-watt gas-filled Mazda lamp operating at a temperature of about 2,400° C. Although substantially correct for the samples tested, they would necessarily vary somewhat for other samples of different thickness and degrees of coloration, so that they can be taken only as a general guide for comparative purposes.

TABLE I.

Kind of Glass.	*Thickness in Inches.*	*Per Cent. Heat Rays Transmitted.*
Clear white mica	0·004	81
Clear window glass	0·102	74
Flashed ruby	0·097	69
Belgian pot-yellow	0·126	50
Cobalt-blue	0·093	43
Emerald-green	0·1	36
Dark mica	0·007	15
Corning G 124 J glass	0·095	10
Dark noviweld	0·096	4
Pfund gold plated	0·114	0·8

We now come to the invisible ultra-violet rays, which are principally to be feared, not only because they are invisible, but because, as previously stated, we have no organ or sense for detecting them, and we can only trace their existence by their effects. In all cases, however, when we are forewarned of their presence they are very easily shielded, for there are only a few substances which are transparent both to the visible light and to ultra-violet radiation. Foremost among these latter substances, because it is most common, is clear natural quartz, or rock crystal, from which the so-called "pebble" spectacle lenses are made.

Fluorite and selenite are also transparent to ultra-violet rays, but these crystalline minerals are rare and not in common use. However, a moderate thickness of ordinary clear glass, sheets of clear or amber mica, are opaque to these dangerous rays. As a case in point, it is well known that the mercury vapour lamp, when made with a quartz tube, is an exceedingly dangerous light to the eye, being a prolific source of ultra-violet radiation, so that when it is used for illumination it is always carefully enclosed in an outer globe of glass; when the mercury vapour lamp, however, is made with a clear glass tube, it is a harmless if not very agreeable source of light, because the outer tube of clear glass is opaque to the ultra-

violet rays that are generated abundantly within it by the highly luminous mercury vapour.

When operating with a source of light which is known to be rich in ultra-violet rays, such as the iron arc in welding operations, it is not sufficient to guard the eyes with ordinary spectacles, because these invisible rays are capable of reflection just the same as visible light, and injury may easily ensue from slanting reflections reaching the eyes behind the spectacle lenses. Goggles that fit closely around the eyes are the only sure protection in such cases. Also, when using a hand shield, such as that shown in Fig. 124, the shield should be held close against the face and not several inches from it.

It may here be mentioned that the ultra-violet rays, when they are not masked or overpowered by intense visible light, produce the curious visible effect termed "fluorescence" in many natural and artificial compounds—that is, these rays cause certain compounds to shine with various bright characteristic colours, when by visible light alone they may appear pure white, or of some weak neutral tint. Thus, natural willemite, or zinc silicate, from certain localities (which may also be made artificially) shows a bright green colour under the light from a disruptive spark between iron terminals, whereas this compound is white, or nearly so, by visible light. Also, all compounds of salicylic acid, such as the sodium salicylate tablets which may be bought at any drug store, are pure white when seen by visible light, but show a beautiful blue fluorescence under ultra-violet rays. Many other chemical compounds could be mentioned which possess this curious property, but the above substances will suffice to illustrate the effect of fluorescence produced by ultra-violet rays and by which these rays may be detected. It must, however, be noted that these substances will only show their fluorescent colours very faintly when viewed by the light of low-tension iron arc used in welding, because the intense light of this arc will overpower the weaker effect of the invisible ultra-violet rays. The true beauty of fluorescent colours can only be seen under a high-tension disruptive discharge between iron terminals, the invisible light in this case being weak while the ultra-violet rays are comparatively intense.

Summarising the effects of means for eye-protection against various harmful radiations, particularly associated with welding operations:

(1) The intense glare and flickering of the visible rays should be softened and toned down by suitable coloured glasses selected by an expert and having a depth of coloration which shows the clearest

definition combined with sufficient obscuration of glare, which last feature can best be determined by the individual operator.

(2) When infra-red rays are present to a dangerous degree a tested heat-absorbing or heat-reflecting glass should be employed, either in combination with a suitable dark-coloured glass, when a glaring visible light is present, or by itself in cases where the visible rays are not injuriously intense.

(3) In guarding the eye from dangerous ultra-violet rays it must be noted carefully that "pebble" lenses are made from clear quartz, or natural rock crystal, and this material, being transparent to these rays, offers no protection against their harmful features. On the other hand, ordinary clear glass is a protection against these rays when they are not very intense, but dark amber or dark amber-green glasses are absolutely protective. Glasses showing blue or violet tints should be avoided except in certain combinations wherein they may be used to obscure other colours.

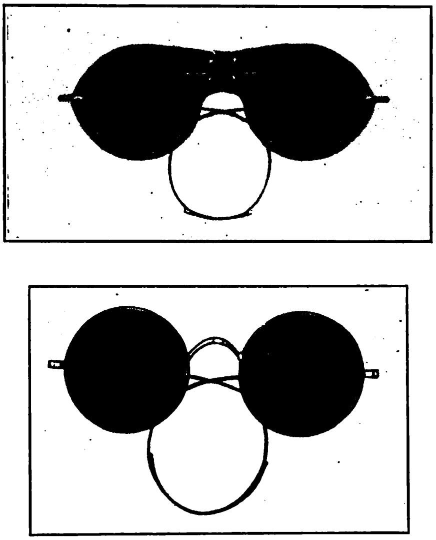

FIG. 129.—GOGGLES: 65 H, 76 H.

No. 47 H goggles are light, rust-proof, sanitary, strong, and perfectly fitting. They are fitted with essentialite amber-coloured lenses which afford full protection to the eyes and cover-glasses which protect coloured lenses.

No. 48 H goggles have the wire shield and other metal parts covered with chamois; nose-piece is soft leather.

No. 49 H goggles have aluminium frame, are very light in weight, and are exceedingly popular with welders.

No. 65 H spectacles have a nickelled steel frame and flexible ear-holds. Fitted with amber lenses, they are very light and comfortable to wear.

No. 76 H spectacles are fitted with essentialite amber lenses, have flexible ear-holds and light fibre frame, making them very popular with welders doing light work.

CHAPTER XXXIX

MIRROR WELDING

MIRROR welding is used in some of those rare cases where breaks and fracture occur in inaccessible places, in which ordinary methods could not be adopted. This method is quite a new one, and not known to many, and it is useful in many cases where dismantling would have to take place in ordinary welding. It is used where the space between the article for welding and the obstructing surface is too small.

The operator is not able to get between the two surfaces, nor could the article be turned. Sometimes two or three mirrors are used together, and set at different angles, so as to facilitate ease in welding, and this adjustment has to be made very accurately so that the operator can do the welding with ease, with the welding line always in view. It is very important that the operator has everything in proper order and in the exact position for welding, so that during the welding there should be no stopping.

It may occur in some instances where the welding has to be done in higher places than ordinary ones. Precautions must therefore be taken to secure stability of the structure used.

In most cases of mirror welding, dissolved acetylene compressed in cylinders (the same as oxygen) is used. Usually these repairs are far from the factory, and in places where an acetylene generator would not be allowed. In case the dissolved acetylene is used, an acetylene regulator would be required for the acetylene cylinder. These acetylene regulators have a left-hand screw at the coupling and the regulator is painted red, so as to distinguish them from the oxygen regulators (painted black).

The operator must study carefully the whole job that he has in hand, seeing whether it is necessary to preheat the article and to guard against unequal and invisible stresses and strains. See if the metal is ¼ inch thick or over; if so, it must be bevelled: in the instance which we are referring to it would be difficult to bevel. Hence, if a sound weld is to be made the bevelling must be accomplished. It can be done by the cutting blowpipe, which, if the handl

of the cutter is held parallel to the pipe now being welded, and the cutter head pointed at 45 degrees to the point of welding, will bevel one side of the line of welding; the cutter should now be taken to the opposite side and the operation repeated. This should be clear of oxide before starting to weld.

In welds of this description there must be two operators, one each

Fig. 130.—Showing the Principle of Mirror Welding with Specially Arranged Filler Rod.

side, one using the blowpipe and the other the welding-rod. Special care must be taken by both operators in the finding of the correct point on the line of welding through the mirrors, and must not, under any circumstances, withdraw their visions from the mirrors until the welding line has been completed.

A smaller blowpipe than usual should be used, as in all vertical and overhead welding the melted metal must not get overheated

or it will become too fluid, will not adhere, will fall from the weld, and the metal will be burnt and cause a larger space to be filled up, and it would be oxidised, burnt, and cinderised.

All that is necessary is to heat as small a surface as possible, not more than $\frac{1}{4}$ inch from the bevel (only heat the outer surface to about 1,000° C.). Before starting to do any welding it is necessary

Fig. 131.—Mirror as Applied to the Pipe heretofore Described.

to see that all the equipment is in perfect order; a lighted torch should be tried to see for certain that it is correct for proceeding.

The welding should be commenced at $\frac{1}{2}$ inch below the break or fracture: this will ensure that the break or fracture will not extend farther. Assuming that one has got all correct, and the trial is satisfactory, welding should now go forward, remembering that one must have a perfect neutral flame, neither oxidising nor carbonising, and the flame must be kept up for certain while welding. An

oxidising flame causes adhesion, lack of penetration, oxidation, burnt and cindered weld, and the tests will fail.

The welding-rod must be absolutely pure, free from phosphorus, sulphur, manganese, and other impurities; the size must be determined by the thickness of the metal to be welded; several rods should

FIG. 132.—INTERNAL WELDING OF A BOILER, WITH A MIRROR.

be kept at hand before starting welding. Welding may now be started; the blowpipe must be kept on the particular welding line until such time as the bottom is melted, when the bottom is found at the starting-point; there should be no mistake about the line being continued from the bottom of the weld.

The welding must be homogeneous, starting at the bottom as

previously stated, and as soon as this is melted add welding-rod, previously heated, in the bevel and move the blowpipe forward with an elliptical sweep, keeping it close in the line of the welding; do not let the white tip touch the metal, but keep it $\frac{1}{8}$ inch from it, and go steadily forward, filling up the bevel uniformly with the feeding-rod until the end of the weld is reached. There must be no stoppage whatever, while welding the line fractured. If it is done quickly and filled in as the welding proceeds, with no stoppage, the weld will be a success—neat and strong.

As soon as the welding is completed it is necessary that it be heated to 950° C. and allowed to cool slowly, free from air.

The mirror welding of a boiler, as shown in Fig. 132, is one that needs every care and consideration; more so than the pipe job previously referred to, because a boiler has to stand very severe tests and strains during its working under steam. Another important point in these boiler cases is expansion and contraction and the avoiding of internal and invisible strains. In the welding of this boiler it must first be made thoroughly clean; all deposited scale that has accumulated must be removed from the fracture and surroundings, and the line of welding must be filed to remove all rust, leaving it bright and smooth.

Before welding can take place it is necessary to preheat a large area of the boiler internally so that the expansion and contraction may be spread over a larger area than the small confines of the weld. In this case it would be difficult to bevel the edges of the fracture; with the cutting blowpipe, therefore, in place of the bevelling, a size larger blowpipe may be used to penetrate right through the metal.

Before preheating, it is necessary to have all equipment ready, the mirrors fixed temporarily and marked at the proper angle, and the blowpipe tried in position for welding. This preheating should be carried out by putting a fire inside the boiler until it reaches the temperature of 950° C. When this temperature is reached, immediately put back the mirrors in place to the angle previously marked and commence welding without delay, and see that the temperature does not get below 800° C., or cracks or fractures will take place.

The welding should be started at $\frac{1}{2}$ inch beyond the line of welding so as to prevent the crack or fracture extending farther than the present line of welding. It is not necessary to have two operators on a job like this. The blowpipe is to be one size larger than is usual for the thickness of metal being welded, and the pressure of oxygen to be slightly less than that stated on the blowpipe. First, the surroundings of the crack or fracture should be heated to about

1,000° C., a little above the preheating temperature, and then start welding at the point previously referred to; this point takes more heating than the other part of the welding line.

There are difficulties of lack of penetration, bad joining, blowholes, and interposition of oxide. Lack of penetration is a frequent occurrence. There is, however, no justification for this, if operators will only go to the bottom of the weld in all cases. Interposition of oxide is a common occurrence, and all operators should study this and make test pieces until they are satisfied that there is no interposition. It occurs, chiefly, with excess of oxygen and using too large a blowpipe. The oxide formed through these errors is imprisoned in the metal. It is very important to see that during the welding no adhesion takes place and full penetration has been observed, that there is no oxidation nor blowholes, and that no part of the weld has been gone over twice without adding the welding-rod. When the welding is completed, the temperature should be immediately taken, and whatever it is it must be raised to 950° C. by putting a fire in the boiler, then allowed to cool slowly, free from air. When cold, test by hydraulic pressure to double the working pressure.

Assuming that welding is now starting, the operator must start just below the fracture line, get well hot over an area of 3 × 3 inches before melting at the starting-point—this will increase the speed of welding—penetrate fully, keeping the tip of the blowpipe vertical and at an angle of 40 degrees, which will just suit the fracture, go along slowly and regularly with a gyratory movement, adding the necessary welding-rod, filling the fracture to its greatest extent with a little extra coating to give more strength; be sure that there is no stoppage; the molten metal must be semiplastic and not cinderised in any way, or too fluid—just at a temperature that will scarcely run; a good weld will then be obtained.

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